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editorial

Trusting STEM Experts and Authorities in the Age of "Fake News"

Dear *SSMA* Journal Readers:

Currently, there seems to be an ongoing trend for the public to question the expertise and authority of STEM professionals (including whether they are "experts or authorities" at all!) by asking, "Why should we believe them?" As asked by Kahan, Jenkins-Smith, and Braman (2011, p. 1), "When empirical assessments of risk and risk abatement are exactly what members of the public are fighting about, why is the prevailing opinion of scientists—on questions only they are equipped to answer—so infrequently treated as decisive?" Kahan et al. (2011) explain that "cultural cognition," or the idea that individuals are disposed to selectively credit or dismiss evidence of risk in patterns that fit values they share with others, shapes their beliefs about the existence of scientific consensus. Moreover, we are living in the so-called "information age," where large amounts of information are widely available to many people, largely through computer technology. This is, in truth, also contributing to this phenomenon of skepticism (Alvarez, 2017). The question for us, as STEM educators, then, is: "How do we help students to become adept at circumventing the morass of information both good (i.e. empirical research) and bad (i.e. 'Fake News') to know what to believe?"

As STEM educators, we are continuously focused on developing our students' problem-solving, critical thinking, and rational thinking skills. These proficiencies are becoming increasingly important as our world becomes ever more complexly interconnected. In fact, Jere H. Lipps (2004) argues that "Living well requires that we be able to evaluate our environment rationally." Likewise, these are skills that STEM "experts and authorities" have developed and utilized to advance knowledge in the context of "cultural cognition."

So we ***must*** address the skepticism of people. Let us begin by taking a look at a few definitions:

- ***Problem solving*** is the process or act of finding a solution to a problem (Problem solving, 2017).
- ***Critical thinking*** is disciplined thinking that is clear, rational, open-minded, and informed by evidence (Critical thinking, 2017).
- ***Rational*** is agreeable to reason; reasonable; sensible; having or exercising reason, sound judgment, or good sense; being in or characterized by full possession of one's reason; sane, lucid (Rational, 2017).
- An ***expert*** is a person who has special skill or knowledge in some particular field; specialist; authority: a person possessing special skill or knowledge; trained by practice; skillful or skilled (Expert, 2017).
- ***Authority***: an accepted source of information (Authority, 2017).

In the context of these definitions and as we continue to analyze with our students the questions of "What makes a person an expert or an authority?" as well as the related question of "Why should we believe them?" we examine criteria for "judging" experts and authority (Lipps, 2004):

- Does the expert/authority produce ***independent evidence*** to support their claims?
- Does the expert/authority have ***proper credentials*** demonstrating their expertise in the relevant field?
- Does the expert/authority have ***proper affiliations***?
- Has the experts/authorities work been ***peer-reviewed***?
- Does the expert/authority have a past record of making ***rational claims*** backed by evidence?

We look to professional organizations for guidance beginning with our own, the School Science and Mathematics Association (SSMA, 2011). SSMA focuses on building and sustaining a community of teachers, researchers, scientists, and mathematicians. The ***proper credentials*** of the members of this ***multinational*** community range from state teaching certification and licenses awarded after successfully completing rigorous, nationally accredited teacher education programs to tenured professors and researchers from public and private colleges and universities. This membership provides the ***proper affiliation*** that warrants the ***authority*** of the members by

Table 1
Alignment of Research Components

NGSS Practices (2013)	Standards for Quality Research (2005)	ALA Framework (2016)
Asking questions (for science) and defining problems (for engineering)	Pose a significant, important question that can be investigated empirically and that contributes to the knowledge base.	Research is iterative and depends upon asking increasingly complex or new questions whose answers in turn develop additional questions or lines of inquiry in any field.
Developing and using models	Base research on clear chains of inferential reasoning supported and justified by a complete coverage of the relevant literature. Ensure the study design, methods, and procedures are sufficiently transparent and ensure an independent, balanced, and objective approach to the research.	Searching for information is often nonlinear and iterative, requiring the evaluation of a range of information sources.
Planning and carrying out investigations	Test questions that are linked to relevant theory. Apply methods that best address the research questions of interest.	Searching for information requires the mental flexibility to pursue alternate avenues as new understanding develops.
Analyzing and interpreting data	Use appropriate and reliable conceptualization and measurement of variables.	Information possesses several dimensions of value, including as a commodity, as a means of education, as a means to influence, and as a means of negotiating and understanding the world. Legal and socioeconomic interests influence information production and dissemination.
Using mathematics and computational thinking	Provide sufficient description of the sample, the intervention, and any comparison groups.	Research is iterative and depends upon asking increasingly complex or new questions whose answers in turn develop additional questions or lines of inquiry in any field.
Constructing explanations (for science) and designing solutions (for engineering)	Provide the necessary information to reproduce or replicate the study. Submit research to a peer-review process.	Information resources reflect their creators' expertise and credibility, and are evaluated based on the information need and the context in which the information will be used. Authority is constructed in that various communities may recognize different types of authority. It is contextual in that the information need may help to determine the level of authority required.
Engaging in argument from evidence	Evaluate alternative explanations for any findings. Assess the possible impact of systematic bias.	Communities of scholars, researchers, or professionals engage in sustained discourse with new insights and discoveries occurring over time as a result of varied perspectives and interpretations.
Obtaining, evaluating, and communicating information	Adhere to quality standards for reporting (i.e., clear, cogent, complete).	Information in any format is produced to convey a message and is shared via a selected delivery method. The iterative processes of researching, creating, revising, and disseminating information vary, and the resulting product reflects these differences.

fostering their knowledge in their field and, therefore, demonstrating their ***expertise***.

Also, SSMA works to advance knowledge through research in science and mathematics education and their integration as well as inform practice through the dissemination of scholarly works in and across science and mathematics. Table 1 illustrates the alignment of research components from the Next Generation Science Standards

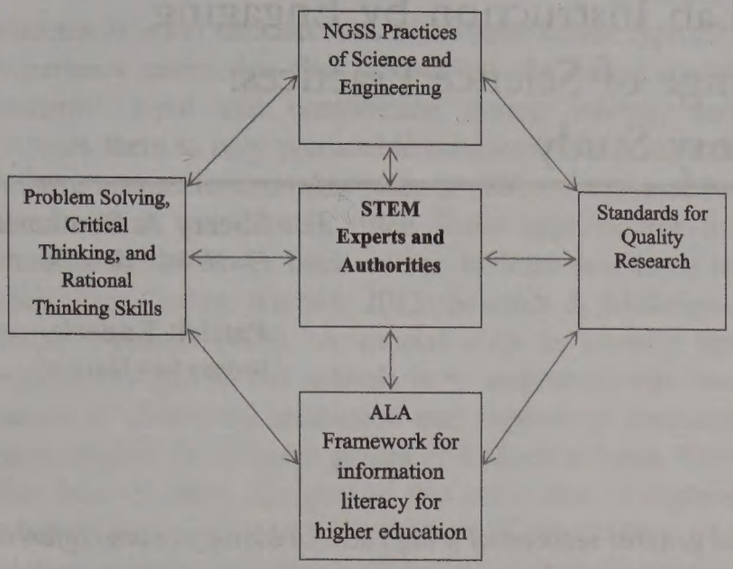
NGSS Practices of Science and Engineering
Problem Solving, Critical Thinking, and Rational Thinking Skills
STEM Experts and Authorities
Standards for Quality Research
ALA Framework for information literacy for higher education

Figure 1. Interplay among research components. [Color figure can be viewed at wileyonlinelibrary.com]

eight practices of science and engineering that are identified as essential for all students to learn (NGSS, 2013); the Standards for Quality Research (Focus, 2005); and the Framework for information literacy for higher education (American Library Association, 2016). These practices, standards, and framework ensure the advancement of knowledge through the development of our own as well as our students' ***problem solving***, ***critical thinking***, and ***rational thinking*** proficiencies. Moreover, *School Science and Mathematics* has been informing practice through the dissemination of scholarly manuscripts since 1901! The SSMA journal is an ***international*** journal emphasizing ***research***. Our journal publishes articles ***backed by evidenced*** determined to be ***rational*** through a rigorous ***peer-reviewed*** process.

In conclusion, we can assist our students in becoming more adept at circumventing the morass of information both good and bad to know what to believe by analyzing with them the rigor expected of researchers and practitioners that develops "experts and authorities" to validate that they can be trusted. Simultaneously, we must support the intellectual progress of our students as they enter adulthood and society by demonstrating and requiring from them the same level of quality documented in Table 1. Figure 1 illustrates the interplay among these research components. Finally, we as STEM "experts and authorities" must persist in communicating effectively with the public through our work in research and practice as we continue to influence policy in science and mathematics education at local, state, and national levels.

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Promoting Equitable Biology Lab Instruction by Engaging All Students in a Broad Range of Science Practices: An Exploratory Study

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This study examines what students enrolled in the honors and general sections of a high school biology course offered at the same school learn when they have an opportunity to participate in a broad or narrow range of science practices during their laboratory experiences. The results of our analysis suggest that the students enrolled in the general sections of the course made similar or larger gains than the students enrolled in the honors section of the course in their abilities to plan and carry out an investigation, argue from evidence, and write a science-specific persuasive essay when these students had an opportunity to participate in a broad range of science practices. These findings suggest that laboratory experiences that give students an opportunity to participate in a broad range of science practices, although considered challenging by many teachers, have the potential to help all students become more proficient in science. The article concludes with a discussion of the implications of this study for classroom instruction and educational policy.

The *New Framework for K-12 Science Education* (National Research Council [NRC], 2012) calls for all students to learn about science by "doing science." In an effort to capture what "doing science" entails, the *Framework* describes a collection of practices that broadly represent some of the key activities that scientists engage in to develop new knowledge or to solve problems. These practices include asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics, constructing explanations, engaging in argument from evidence, and obtaining, evaluating and communicating information. Students will need to learn how to participate in these important practices in order to reach the performance expectations found in the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013). Teachers, as a result, will need to enact lessons that give students more opportunities to learn how to use the practices of science to explore and explain the natural world inside the classroom (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014; Osborne, 2014). However, if the current goal of science education in the United States is for *all* students to reach the NGSS performance expectations, this type of classroom instruction cannot be reserved for only a select few. This call for all students to learn science by doing science is considered by many to be a critical and much needed shift in the nature of classroom instruction. The authors of the *Framework*, for example, emphasize the importance of making this shift in focus when they write, "arguably, the most pressing challenge facing U.S. education is to provide all students with a fair opportunity to learn" (NRC, 2012, p. 282).

Although there is a wide body of research that suggests that "all individuals, with a small number of notable exceptions, can engage in and learn complex subject matter" (NRC, 2012, p. 280), many teachers think focusing on complex material or using instructional approaches that give students an opportunity to participate in the practices of science is too challenging for low-performing students (Schmidt & McKnight, 2012). For instance, teachers often claim that high performing students are the only ones that can successfully argue from evidence because it is too difficult for all but the most capable students (Sampson & Blanchard, 2012). The instruction that teachers provide for students who are placed into lower track courses, as a result, is often fundamentally different and tends to be far more simplistic than the instruction that students in honors or advanced placement courses experience (Yerrick, 2000).

Yerrick (2000) argues that "excellence in science instruction" (p. 808) is often reserved for the elite, so that

students in lower track sections of the same course typically experience instruction that focuses on the basics, limits students' input and contribution during lessons, and exposes them to only predictable outcomes. The nature of science instruction that takes place in different tracks of the same course, as a result, often limits opportunities for students in the lower track course to learn and leads to social stratification (Gorski, 2013; Schmidt & McKnight, 2012; Yerrick, 2000). A crucial step in closing the opportunity gap in our schools is to understand how the nature of classroom instruction can support or constrain opportunities for different groups of students to learn. With this issue in mind, the goal of this study was to explore what students who were tracked into different sections of a biology course learn when both groups of students have an opportunity to learn science by participating in a broad range of science practices.

Theoretical Framework

This study is grounded in social constructivist theories of learning (see Anderson, 2007; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Scott, Asoko, & Leach, 2007). This perspective asserts that learning science involves "people entering into a different way of thinking about and explaining the natural world; becoming socialized to a greater or lesser extent into the practices of the scientific community with its particular purposes, ways of seeing, and ways of supporting its knowledge claims" (Driver et al., 1994, p. 8). The learning of the disciplinary core ideas and the practices of science therefore involve both personal and social processes. The social process of learning involves exposure to the language, representations, concepts, and the practices that make science different from other ways of knowing. This process requires input and guidance about "what counts" from people that are familiar with the goals, norms, and epistemological commitments that define science as a community of practice. Thus, learning is dependent on supportive interactions with others. The individual process of learning, in contrast, involves the construction of new knowledge and new ways to explore the unknown through the appropriation of important ideas, modes of communication, modes of thinking, and practices for generating new knowledge by making sense of an experience and integrating new views with the old.

This theoretical perspective has two important implications for instruction with respect to how students learn science inside the classroom. First, students must have opportunities to use disciplinary core ideas and participate in the practices of science to learn about them. Science laboratories can be an ideal setting for the social construction of knowledge and directly investigating natural phenomena using the tools, models, theories, and modes of communication that are valued within a particular discipline (Blanchard et al., 2010). Second, students must develop an understanding of what makes certain aspects of a practice more productive or useful than others within a particular discipline and why. For example, scientists often plan to control variables and conduct multiple trials when designing a scientific investigation. It is therefore important to not only engage students in a science practice, such as designing an investigation, but to also help them understand why certain strategies or techniques associated with each practice, such as controlling variables or including multiple trials, are more productive and useful than others in specific situations. Without a focus on both the how and the why, learners never really develop a "grasp of practice" (Ford, 2008) that they can use in novel situations.

Background

Nature of Current Classroom Instruction

Current research indicates that science teachers rarely, if ever, give students opportunities to participate in the disciplinary practices of science (Kiuhara, Graham, & Hweken, 2009; Weiss, Banilower, McMahon, & Smith, 2001). This trend holds true even for laboratory experiences—a space in which one might expect to see students engaged in the practices of science. The authors of *America's Lab Report* (NRC, 2006), for example, found that "the quality of current laboratory experiences is poor for most students" (p. 6) and that most laboratory experiences are highly prescriptive in nature and are intended to demonstrate or verify previously addressed content. Many science educators found these findings to be highly problematic at the time, especially in light of the calls for students to learn science through inquiry that were made in the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1989) and the *National Science Education Standards* (NRC, 1996) over a decade earlier.

Recent results from the *National Survey of Science and Mathematics Education* (NSSME; Banilower et al., 2013), which was administered to approximately 3,700 practicing middle and high school science teachers in the United States, suggest that the nature of laboratory experiences has not changed much since the release of the *America's Lab Report* in 2006. The results of the NSSME, for example, indicate that 80% of the teachers who completed the survey reported that they emphasize understanding science concepts in the course they teach and 50% focus on learning science process skills (i.e., observing and measuring), but only 18% report that they help their students learn to support their claims with evidence (p. 71, 75). In addition, the results of

the NSSME indicate that even though 70% of the surveyed teachers reported doing laboratory activities at least once a week, only 58% give students an opportunity to visually represent or analyze data, 21% encourage their students to reflect on learning through writing, 9% reported that they require their students to give oral presentations, and only 8% engaged their students in problem-based learning activities (p. 76). These findings suggest that most students in the United States do not have the opportunity to share the process and products of an inquiry with others in a manner that is consistent with the norms and epistemological commitments of science. Although the practices described in the *Framework* (NRC, 2012) are considered by many science educators as fundamental in terms of what it means to do science (Indrisano & Paratore, 2005; Saul, 2004) and doing science is the embodiment of what some authors describe as authentic science learning (Crawford, 2014; Jiménez-Aleixandre & Erduran, 2008), few students have an opportunity to engage in a wide range of practices or to learn why various aspects of each practice are more useful or valuable than others when attempting to develop, test, or refine scientific knowledge.

Inequitable Learning Opportunities

While authentic laboratory experiences are uncommon in middle and high school science classrooms, students who have been tracked into general or remedial science courses have even fewer opportunities to learn how to participate in the practices of science. Yerrick (2000), for example, describes how high-performing students and students enrolled in honors or advanced sections of a course are expected to engage in rigorous science talk while in school, whereas low-performing students and students tracked into general or remedial sections are expected to learn a set of facts and basic process skills. The work of Barton and colleagues (2000, 2010) also draws attention to the fact that students in urban schools often experience instruction that does not give them access to the analytical and discursive tools of the culture of science. By enacting such instruction, teachers actually limit students' ability to assume membership in the culture of science and their access to learning about and through the practices of science. This is problematic because Barton and Tan (2010) have shown that students in urban schools, who are typically labeled as low performing or "at-risk," are able to quickly appropriate the discursive tools of science and develop a science identity when they have rich opportunities to participate in the practices of science. These findings, when taken together, suggest that low-performing students are underserved by the instruction they typically experience, especially when they are tracked into the general or remedial sections of a science course.

Another factor that contributes to inequitable classroom instruction is the teacher's views about students (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003). Sampson and Blanchard (2012), for example, found that teachers tend to think that the practice of arguing from evidence is too challenging for many students, especially for those students enrolled in the remedial or general sections of a course, so it is better to focus on the basics during a lesson and not structure lessons so students have opportunities to evaluate explanations, support claims using evidence, or question the reasoning of others because it might led to confusion. Pimentel and McNeill (2013) also found that the teachers in their study enacted more authoritarian, teacher-centered instruction when they thought their students did not have enough background knowledge or experience with argumentation even though they personally supported a more student-centered vision of instruction. Although these two studies focused mainly on the practice of argumentation, they demonstrate how a teacher's views about different students and what type of instruction is most appropriate or beneficial for different groups of students can limit opportunities for some students to participate in the practices of science.

Our review of the literature, in summary, indicates that the nature of current classroom instruction in science is not well aligned with current recommendations for making science more meaningful, equitable, and inclusive. Moreover, instruction for lower track students tends to be less cognitively demanding and leads to social stratification in which some students have far fewer opportunities to learn (Banilower et al., 2013; Schmidt & McKnight, 2012; Yerrick, 2000). Such unequal opportunities lead to questions of what students enrolled in general or remedial sections of a science course might learn if they had access to the same high quality laboratory instruction that is usually reserved for students enrolled in honors or advanced sections.

Objective and Research Questions

We therefore decided to examine what students who were enrolled in either the general or honors sections of a biology course learned over an academic school year when exposed to the same laboratory instructional approach. In two classrooms at one school, the teachers used a prescriptive approach to laboratory instruction that emphasized data collection and analysis. In two classrooms at another school, the teachers used an approach to laboratory instruction called Argument-Driven Inquiry,

Table 1
Characteristics of the Schools

School	Total Enrollment	Race (% of enrollment)					Percent Free or Reduced Lunch Eligibility	2010–11 School Grade*
		White	Black	Hispanic	Asian	Other		
A	1,877	60.6	30.2	3.2	3.2	2.7	17.8	B
B	659	50.8	31.4	9.7	2.0	6.1	28.3	A

* School grade based on state accountability and performance outcomes for schools.

which is designed to support students in using core ideas and science practices to explain natural phenomena. The research questions that guided our study were:

1. How does the biology learning of differently tracked students compare when laboratory experiences engage them in a narrow range of science practices?
2. How does the biology learning of differently tracked students compare when laboratory experiences engage them in a broad range of science practices?

Method

We used a convergent mixed methods design (Creswell & Clark, 2011) to qualitatively describe the instruction that took place in two high schools and to quantitatively describe the student learning that occurred in each instructional approach for different groups of students. We selected these two high schools as our study sites because laboratory experiences were a major component of the biology curriculum in both schools, yet the biology teachers at these two schools used laboratory investigations to support learning in different ways. Additionally, in both schools, students were tracked into honors and general sections of the biology course. Based on these existing differences at each school, we wanted to describe the nature of laboratory instruction at each school and examine trends in student learning within each context.

To describe the nature of laboratory instruction, we interviewed each teacher about the number of laboratory experiences in their curriculum, when these experiences were provided to their students, and what they expected their students to do during each one. We also collected copies of their lesson plans and instructional materials from each teacher as part of the interview. Finally, we conducted observations of classroom practice over the course of the school year. To examine student learning, we administered three assessments at the beginning and end of the school year: a content assessment, a performance task, and a writing assessment.

Description of School A

School A was a 9–12 public high school in the southeastern United States. Table 1 displays the breakdown of enrollment, race, free or reduced lunch eligibility, and school grade. Mike and Betty taught Biology at School A. Mike had been teaching at school A for one year before the year of this study, but he had 25 years of experience teaching, having taught high school biology, chemistry, and physics. During this study, he taught four sections of general biology. Betty had worked at this school for several years at the time of this study, with a high school teaching career lasting 11 years. During this study, she taught five sections of biology, two of them being honors sections. All students enrolled in the biology course during the 2011–12 academic year were asked to participate in the study and a total of 100 students agreed. However, owing to high school attrition during the year and high student absenteeism on one of the two days allowed by the assessment administration, complete datasets were collected from 31 students (15 general; 16 honors) for the biology content assessment, 30 students (15 general; 15 honors) for the performance task assessment, and 49 students (22 general; 27 honors) for the biology writing assessment. These students were either in 9th or 10th grade.

Description of School B

School B was a 9–12 charter school in the southeastern United States. Table 1 displays the breakdown of enrollment, race, free or reduced lunch eligibility, and school grade. Helen and Willa taught biology at School B. Helen had been at this school for 15 years, teaching general biology, honors biology, and anatomy courses. During this study, she taught two sections of honors biology. Willa had seven years of teaching experience, one year at this school, teaching general and honors biology. During this study, she taught five sections of biology, including one honors section. All students enrolled in the biology course during the 2011–12 academic year were asked to participate in the study and 117 students agreed; however, owing to incomplete forms and student absenteeism, complete

datasets were collected from 99 students (54 honors; 45 general) for the biology content assessment, 89 students (51 honors, 38 general) for the performance task assessment, and 103 students (57 honors; 46 general) for the biology writing assessment. These students were either in 9th or 10th grade.

Instruments

Student learning over the academic year was measured using three assessments that were each administered at the outset and end of the school year. These assessments were developed in conjunction with tenured biology faculty at a nearby research university to ensure content and construct validity. The biologists also provided an "expert answer" to each question that we used to construct the itemized rubrics and ensure translational validity. See Strimaitis, Enderle, Grooms, and Sampson (2015) for the development and validation process for each instrument.

Content assessment. The content instrument assessed student knowledge and application of biology concepts. The pre-test and the post-test were identical, consisting of eleven free response questions. Each question related to a core idea identified in state and national standards documents for high school biology that was addressed in the curriculum at each school. The core ideas were cell theory, mitosis, photosynthesis, cellular respiration, patterns of inheritance, meiosis, DNA structure, macroevolution, biological species concept, mechanisms of evolution, and nutrient cycles. Each question provided background information related to the core idea, followed by two questions. The first question asked the student to *describe* the science concept underlying the question. The second question asked the student to *apply* understanding of that science concept. The response to each question was scored as either 0 points (inaccurate response), 1 point (insufficient but accurate), 2 points (adequate and accurate), or 3 points (nuanced response) based on the accuracy and the number of elements from the expert answer included in the student answer. Scores on instrument ranged from 0 to 72 points.

Performance task. This instrument prompted students to plan and carry out an investigation, analyze and interpret data, develop an explanation, and argue from evidence. The task was completed individually and included a short paragraph describing a science concept, a research question, and a list of materials available to the student. Open-ended questions prompted the student to record and explain his or her decision-making processes and the results of those decisions. The performance task was scored out of a maximum of 32 points and included subscales to separately assess each student's proficiency in each of the four practices. The pre-test was based on the guiding question: *What kind of animal did the unknown specimen come from: a predatory bird, a perching bird, or something else?* The available materials included footprints from an unknown animal, predatory birds, and perching birds, and various data collection materials. The post-test was based on the guiding question: *Did the unknown skull come from a carnivore, herbivore, or something else?* The available materials included skulls from an unknown animal, from herbivores, and from carnivores, and various data collection materials.

Writing assessment. The writing assessment tasked students to argue from evidence, evaluate information, and communicate information through writing. The assessment included background information, a dataset, and an inaccurate argument generated from the dataset. The prompt directed each student to present a countering argument in response to the inaccurate argument, including appropriate evidence and justification. Photosynthesis was the topic of both the pre-test and post-test. The assessment was scored out of a maximum of 26 points and included subscales to assess the structure of the written argument (0–6 points), the content of the argument (0–10 points), and the writing mechanics (0–10 points).

Data Analysis

We collected information during the teacher interviews to help us understand the nature of laboratory instruction at each school. Our first step was to determine the number of laboratory experiences that each teacher provided and if the number differed by section of the course. Next, we used the framework from Blanchard et al. (2010) to describe the nature of classroom inquiry to classify each laboratory experience. We then developed codes to identify how many different opportunities the students had to participate in the science engineering practices (SEP) found in the *Framework* (NRC, 2012) during each laboratory experience. We focused on the practices of planning and carrying out investigations (SEP #3), analyzing and interpreting data (SEP #4), constructing explanation (SEP #6), and obtaining, evaluating, and communicating information (SEP #8) for this analysis due to the nature of the laboratory experiences. Since many of these practices are complex and consist of multiple components, we used several different codes to identify the various components of these practices. For example, we used three different codes to identify different activities related to the practice of obtaining, evaluating, and communicating information. These included (a) evaluating information presented to them, (b) communicating information through an oral presentation, and (c) communicating information through a written report. Finally, we used the classroom observations

Table 2
The Number and Type of Laboratory Experiences Provided in Each Instructional Approach

Approach	Teacher	Class Sections		Number of Lab Experiences	Type of Laboratory Experiences (Inquiry Level)*			
		General	Honors		Activity (0)	Structured (1)	Guided (2)	Open (3)
Narrow	Mike	4	0	30	19 (63%)	8 (27%)	2 (7%)	1 (3%)
	Betty	3	2	15	13 (87%)	1 (7%)	1 (7%)	0 (0%)
Broad	Helen	0	2	12	0 (0%)	0 (0%)	12 (100%)	0 (0%)
	Willa	4	1	9	0 (0%)	0 (0%)	9 (100%)	0 (0%)

* Inquiry levels for laboratory experiences described in Blanchard et al. (2010).

that we conducted during the academic year to confirm that our analysis of the teachers' comments during the interviews, lesson plans, and instructional materials were consistent with what actually happened inside the classroom.

A triad of researchers scored 25% of the fully blinded set of each assessment and the intraclass correlation coefficient (ICC) was determined (two-way random effects, absolute agreement). An ICC above .6 is considered substantial agreement (Landis & Koch, 1977), and once obtained, the team members scored individually. The ICC for the content, performance task, and writing assessments were .790, .853, and .794, respectively. Paired-samples *t*-tests were used to quantify gains on each assessment. Cohen's *d* effect sizes were calculated and interpreted small (.2), moderate (.5), and large (.8) effects, respectively (Cohen, 1992).

Results

Nature of Instruction in Each School

Mike and Betty reported that their biology students participated in a high number of laboratory experiences (15–30) during the year. Most of these laboratory experiences were verification activities, or Level 0 inquiry (Table 2). As shown in Table 3, the majority of these activities involved data analysis and interpretation, but few involved designing methods to collect data, arguing from evidence or giving an oral presentation. Because students had an opportunity to participate in a narrow range of science practices, this instructional approach is referred to as "narrow" in all tables and figures. It is important to note that Betty used the same laboratory experiences in both her general and honors sections of the course.

Helen and Willa, in contrast, planned laboratory experiences using an instructional model called Argument-Driven Inquiry (ADI) (Sampson et al., 2014). Helen and Willa described all their biology laboratory experiences as guided or level 2 inquiry investigations (Table 2). Blanchard et al. (2010) describes level 2 inquiry as an investigation where the teacher provides the investigation question, but the data collection methods and interpretation of results are open to the student. Each laboratory investigation spanned several class periods and students engaged in several practices of science. As shown in Table 3, every investigation involved students in planning a method to collect data, analyzing and interpreting data, arguing from evidence, evaluating information, and giving an oral presentation. Additionally, almost every investigation required the students to write about their investigation and its outcomes. Because students had an opportunity to participate in a broad range of science practices, this instructional approach is referred to as "broad" in all tables and figures. Willa, much like Betty, used the same laboratory experiences in both her general and honors sections of the course.

Student Learning Gains

We examined student gains on each assessment by grouping students according to enrollment in honors and general class sections. Table 4 displays the results of the paired-samples *t*-tests for the student groups for each instructional approach on each assessment. Figure 1 displays the mean pre-test and post-test scores on the (a) content knowledge assessment, (b) performance task, and (c) writing assessment for students enrolled in the honors and general biology sections.

Students enrolled in both the honors and general biology classes at school A (narrow instructional approach) made significant gains on the content knowledge assessment. This instrument, as noted earlier, measured their knowledge of and ability to use the big ideas in biology (see Table 4 and Figure 1a). The effect size for each group was large (Cohen, 1992). Students enrolled in the honors classes made significant but moderate gains on the performance task assessment. The students enrolled in the general classes, however, did not improve in their ability to plan and carry out a scientific investigation, analyze and interpret data, and construct a scientific explanation (see

Table 3
Opportunities to Participate in the Practices of Science within each Instructional Approach

Teacher	Number of Lab Experiences	Opportunities to Participate in Scientific Practices (NGSS Practice #)*						
		Plan an investigation (SEP #3)	Analyze and Interpret Data (SEP #4)	Construct Explanations (SEP #6)	Argue from Evidence (SEP #7)	Evaluate Information (SEP #8)	Communicate Information (oral) (SEP #8)	Communicate Information (written) (SEP # 8)
Mike	30	5 (17%)	27 (90%)	11 (37%)	6 (20%)	3 (10%)	3 (10%)	12 (40%)
Betty	15	0 (0%)	10 (71%)	1 (7%)	1 (7%)	0 (0%)	1 (7%)	1 (7%)
Helen	12	12 (100%)	12 (100%)	12 (100%)	12 (100%)	12 (100%)	12 (100%)	10 (83%)
Willa	9	9 (100%)	9 (100%)	9 (100%)	9 (100%)	9 (100%)	9 (100%)	7 (78%)

* We did not ask teachers about practice 1, 2, and 5 in this study.

Table 4 and Figure 1b). Neither the honors group nor the general group made a significant gain on the biology writing assessment (see Table 4 and Figure 1c).

Students enrolled in the honors and general sections of the biology course offered at school B (broad instructional approach) made significant and large gains on the content knowledge assessment (see Table 4 and Figure 1a) much like the students at school A did. The students enrolled in the honors and general sections of biology at school B, however, also made significant and moderate gains on the performance task assessment (see Table 4 and Figure 1b). In addition, both groups of students at school B made significant but small gains on the writing assessment (see Table 4 and Figure 1c).

Limitations and Discussion

We focused on student growth in both content knowledge and in a broad range of science practices, as described in the *Framework* (NRC, 2012). It was important to focus on multiple aspects of student learning because different instructional approaches may promote or constrain different aspects of student learning and few studies have examined differences in learning for different groups of students using multiple measures. This choice, however, required us to develop and administer three assessment instruments at the beginning and end of the school year because existing measures used by the school and the state only focus on content knowledge. Giving these assessments required investment of potential instructional time. The teachers using the narrow instructional approach allocated two days to administer the three assessments. We therefore could only administer two of the three assessments to each student. This constraint, in addition to a high rate of absenteeism on the testing days, resulted in a small student sample for the narrow instructional approach. With these limitations in mind, we will now provide a tentative answer for each research question based on the results that we provided earlier.

How Does the Biology Learning of Differently Tracked Students Compare When Laboratory Experiences Engage Them in a Narrow Range of Science Practices?

Mike and Betty described the nature of the laboratory experiences they provided to their students as largely confirmation labs that could be described as Level 0 or Level 1 inquiry (see Table 1). Students regularly engaged in analyzing and interpreting data during laboratory instruction, but they had limited opportunities to participate in the other science practices (see Table 2). Mike and Betty's qualitative descriptions reflect national trends

Table 4
Results of Paired-samples t-test Analyses for Honors and General Classes for Each Instructional Approach on Each Assessment

Instructional Approach	Assessment	Class Section	Pre Mean	SD	Post Mean	SD	*t* statistic	*p*	*d*†
Narrow	Content Knowledge	Honors	4.22	3.51	9.11	4.81	$t(17) = 5.52$	<.001*	1.30
		General	.85	.90	3.85	3.13	$t(12) = 3.95$	.002*	1.10
	Performance Task	Honors	11.27	4.22	14.80	6.06	$t(14) = 2.92$	.011*	.75
		General	10.73	3.49	10.93	4.94	$t(14) = .19$	.856	–
	Writing Assessment	Honors	13.44	5.12	13.96	4.51	$t(26) = .52$	.605	–
		General	11.59	5.82	12.50	5.35	$t(21) = .60$	.554	–
Broad	Content Knowledge	Honors	4.65	3.10	19.07	5.79	$t(53) = 18.1$	<.001*	2.46
		General	2.91	2.03	13.62	8.37	$t(44) = 9.69$	<.001*	1.45
	Performance Task	Honors	18.12	4.70	21.39	4.23	$t(50) = 4.40$	<.001*	.62
		General	12.38	5.68	15.78	4.20	$t(36) = 3.30$	.002*	.54
	Writing Assessment	Honors	16.23	4.18	17.79	3.91	$t(56) = 2.24$	.029*	.30
		General	11.35	4.26	13.24	3.84	$t(51) = 6.12$	.012*	.39

*Significant at the $p < .05$ level.
†Cohen's *d* values of .2, .5, and .8 are interpreted as small, medium, and large effect sizes, respectively.

describing the nature of instruction in science classrooms (Banilower et al., 2013). When students participated in such laboratory experiences, students grouped in honors and general sections made significant large gains in biology content knowledge (see Figure 1a). Given the focus on confirming biology content through laboratory experiences, the results that both groups of students learned biology content when the instructional approach focused on learning content are not surprising. Content knowledge is generally the aspect of science proficiency that is privileged on tests developed at the school, state, and national levels (Corliss & Linn, 2011).

We did not expect students who participated in laboratory experiences that focused on a narrow range of science practices to make large gains on the performance task or the writing assessment because they did not have much opportunity to participate in the assessed practices (see Table 2). A large body of literature has established that most students do not learn how to plan and carry out an investigation, construct a scientific explanation, argue from evidence, or write about science content in a manner that is consistent with norms and epistemological commitments of the scientific community if they do have an opportunity to engage in these practices during science instruction (Barton & Tan, 2010; Crawford, 2014; Wilson, Taylor, Kowalski, & Carlson, 2010). In this study, the students in the honors sections and the general sections did not make significant gains on the biology writing assessment (see Figure 1c). However, the students enrolled in the honors section did make a significant gain on the performance task assessment with a moderate effect size (see Figure 1b).

One potential explanation for these findings is that the narrow instructional approach is meeting the needs of students in the honors class, but not the students in the general class. The students tracked into the honors class appear to also be the students who perform well on content tests, which assess how a student can recall and apply biology concepts. The students in the honors classes may have been able to recall learning about how to design and carry out an experiment to construct a scientific explanation from previous readings or lectures and then applied this information on the performance task, without regularly engaging in these science practices during classroom instruction. Perhaps the students who are tracked into the general classes needed to engage in science practices to learn how to participate in them.

It was important to document what students learned in this context because these data provide a baseline of what students are likely to learn in a classroom where laboratory experiences are consistent with the national trends in instruction (Banilower et al., 2013). This type of instruction, as noted earlier, is not aligned with the vision of instruction outlined in the *Framework* (NRC, 2012). Such instruction appears to serve all students in developing biology content knowledge, but it only serves students that already have strong content knowledge in developing proficiency at science practices such as planning and carrying out investigations, analyzing and interpreting data, constructing explanations, and arguing from evidence. This type of instruction, as a result, may actually contribute to the performance gap between students tracked into the honors biology classes and students tracked into the general biology sections.

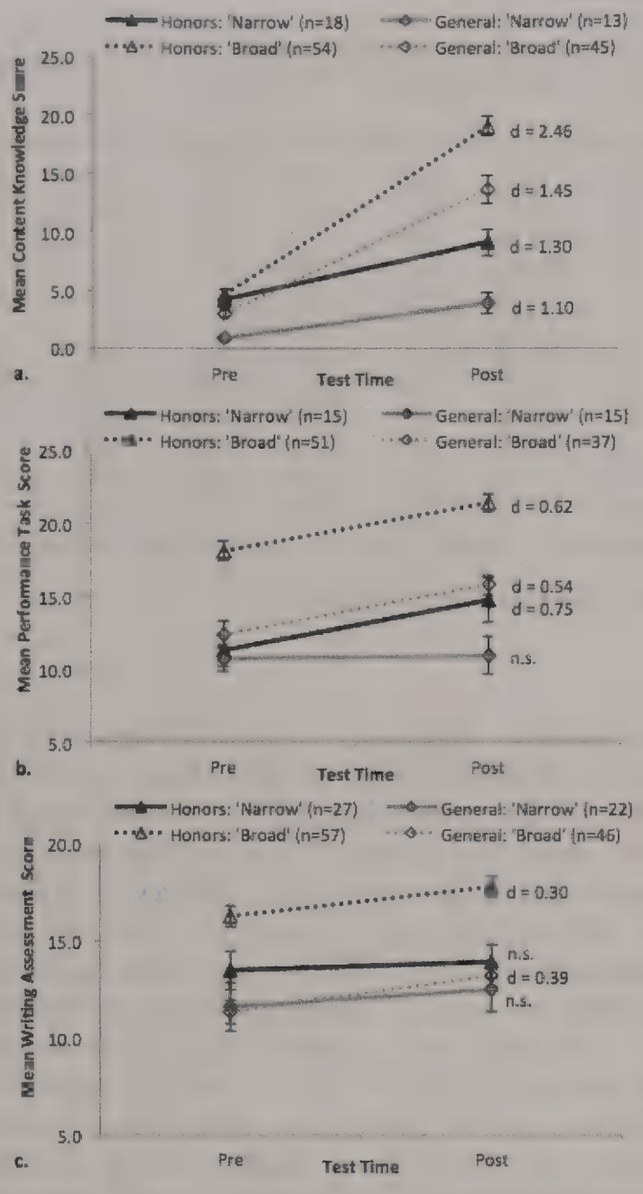

Figure 1. Pre-test and post-test scores for student groups based on class enrollment on the (a) content knowledge assessment, (b) performance task assessment, and (c) writing assessment. Error bars represent ±1 SE; d = effect size for paired-samples t-test; n = sample size.

How Does the Biology Learning of Differently Tracked Students Compare When Laboratory Experiences Engage Them in a Broad Range of Science Practices?

Helen and Willa described the nature of the laboratory experiences they provided to their students as entirely guided (level 2) inquiry (Table 1). These students also had an opportunity to participate in a broad range of science practices during each one of their laboratory experiences (Table 2). The students in this context, in other words, had multiple opportunities to use core ideas to design a method to collect data, analyze and interpret data, construct an explanation, argue from evidence, and communicate about their decision-making processes and the results of those processes) in an attempt to explore and explain the natural world. Helen and Willa's qualitative descriptions of their laboratory instructional practices, as a result, were well aligned with the vision of instruction outlined in the *Framework* (NRC, 2012).

When students engaged in a broad range of science practices to investigate core ideas, both the honors and general class sections made significant large gains in biology content knowledge (see Figure 1a). In addition, the gains made by students enrolled in both the honors and general sections of the course on the content knowledge assessment were much greater, in terms of effect sizes, than the gains made by the students in the honors and general sections who only had an opportunity to participate in a narrow range of practices. This is notable because it indicates that all students can improve their content knowledge when they have opportunities to use core ideas and the practices of science to explore and explain natural phenomena. Moreover, these results challenge the widespread concern that incorporating a greater focus on science practices into the science curriculum, as recommended by the *Framework* (NRC, 2012), will take away from the time needed to teach mandated science content (Jones & Johnston, 2002). Our study indicates that engaging students in a broad range of science practice to investigate core disciplinary ideas supports biology content learning for all student groups.

Additionally, both the students enrolled in the honors sections and the general sections of the course made similar gains on both the performance task and the writing prompt (see Figures 1b and 1c) when they had an opportunity to participate in laboratory experiences that engaged them in a broad range of scientific practices. While the students enrolled in honors and general biology sections started at different places, both groups exhibited the same patterns of growth. In addition, the students enrolled in general sections of biology at school B (broad instructional approach) scored at the same level as the students enrolled in the honors sections of biology at school A (narrow instructional approach) on both the performance task and writing prompt at the end of the year (see Figures 1b and 1c). Although these trends will require additional studies using a different research design to substantiate, they suggest that engaging students in a broad range of scientific practices during laboratory experience has the potential to erase achievement gaps and make biology instruction more equitable. These descriptions of what different groups of students learned when engaged in a broad range of science practices also illustrate how all students, regardless of what course they are tracked into, are capable of engaging in and

developing proficiency in the practices of science while also learning content knowledge.

Implications for Teaching and Learning Science

Our findings address the widespread concern that engaging students in practices of science takes away from the instructional time that is needed to help student learn the content that is a focus of mandated state science assessments. Teachers and administrators often worry that using instructional time to engage students in science practices will lead to lower scores on these assessments because these assessment are designed to measure students' knowledge of concepts, facts, and vocabulary (Jones & Johnston, 2002). Yet, our findings call into question such a view. Our findings suggest that when students engage in a wide range of scientific practices as part of an authentic investigation, they are able to learn science content at the same time, as evidenced in the broad instructional approach. This finding is consistent with other studies that indicate that learning content through inquiry-based instructional approaches fosters content learning for both high and low performing students rather than hindering it (Blanchard et al., 2010; Wilson et al., 2010).

These findings are also important because the performance expectations found in the NGSS (NGSS Lead States, 2013), which are based on the *Framework* (2012), require students to be able to use core ideas and the practices of science at the same time. This shift in focus will require teachers to focus on both content and practices inside the classroom. Although students can learn a great deal of content when teachers use a more traditional approach to laboratory instruction, students will not learn how to participate in the practices of science unless these practices become a focus of classroom instruction. These findings suggest that instructional time can be used more efficiently when teachers focus on the core ideas and practices of science at the same time even though these types of lessons may span multiple class periods.

Furthermore, the significant learning gains displayed by the general biology class sections in the broad instructional approach on all three assessments contradict the long-held concern among many teachers that lessons that engage students in the practices of science are too challenging for some students (Barton, 2003; Pimentel & McNeill, 2013; Prime & Miranda, 2006; Sampson & Blanchard, 2012). These findings add quantitative support to qualitative studies that demonstrated how engaging in science practices can improve student understanding of and proficiency with them, while also developing identities and communities that privilege the epistemic criteria underlying them (Barton & Tan, 2010; Ryu & Sandoval, 2012). Our findings are also important because they can be used to challenge teachers' views about different students and what type of instruction is most appropriate or beneficial for different groups of students.

These findings are also important because many past attempts to close achievement gaps have failed to be successful in terms of addressing the needs of all students. Rather than closing achievement gaps, many approaches such as tracking or focusing on the basics have created opportunity gaps that have placed many groups of students at a greater disadvantage (Lee & Buxton, 2010). As we work to enact the vision of science education described in the *Framework* (NRC, 2012), all students must be given the same opportunity to learn science by engaging in the practices of science, and teachers will need to make sure *all* students have access to this type of instruction. One way to accomplish this goal is to encourage science teachers to use new instructional approaches, such as Argument-Driven Inquiry (Sampson et al., 2014), that are specifically designed to give students an opportunity to learn how to use core ideas and the practices of science to explore and explain the natural world. These types of instructional approaches not only provide teachers with a tool they can use to design lessons that are well aligned with the vision of science instruction found in the *Framework* (NRC, 2012), but they also provide teachers with a way to make their lessons more equitable for the diverse group of students in their classrooms.

Implication for Science Education Policy

It is common practice nationwide to group students by perceived ability or past performance on standardized assessments. This practice is often described as tracking. It is intended to be beneficial for both students and teachers because instruction can be tailored to the needs of students at different levels and it is easier for teachers to create a lesson for a group of students who are all at the same level. For example, teachers can provide extra time or different lessons for students in one class who are struggling and provide extra challenges for the students in another who mastered the content quickly. However, there is little evidence that tracking benefits either low- or high-performing students (Carbonaro, 2005). Instead, current research suggests that the instruction for "lower track" students tends to be less cognitively demanding, gives students fewer opportunities to learn, and leads to social stratification (Banilower et al., 2013; Schmidt & McKnight, 2012; Yerrick, 2000)

Our findings from the broad instructional approach further call into question the assumed benefits of tracking. When students enrolled in the honors and general sections

of the same course experienced the same laboratory instructional approach, both groups made similar learning gains. It appears that there is little reason to sort students into honors and general class sections when all students are capable of engaging in and learning from rigorous, cognitively demanding biological instruction. In addition, the two teachers in our study who taught both honors and general sections of biology (Betty and Willa) reported that they used the same laboratory experiences in both sections. Therefore, these two teachers did not make substantial modifications to their lessons in order to better meet the needs of their students enrolled in the different sections of the course (which is an assumed benefit of tracking). Betty and Willa's decision to use the same laboratory experiences in both sections of the course, however, lead to very different outcomes. In the case of Betty, who used an instructional approach that engaged students in a narrow range of practices, the students enrolled in the general sections of the course learned much less than their peers in the honor section. Willa, in contrast, used an instructional approach that engaged students in a broad range of practices in both sections. This decision enabled the students in the general section to make the same gains as the students enrolled in the honors section did. This finding is important because it suggests that a teacher's decision to use the same type of instruction for all students can either make the classroom more equitable or it can place some students at a disadvantage depending on the nature of the instructional approach the teacher decides to use.

Implications for Future Research

As current efforts call for science curricula and instruction to emphasize the coordination of science content and practices, teachers must make instructional decisions to accomplish this task (Krajcik et al., 2014). Undoubtedly, establishing classroom communities that reflect the norms and epistemological commitments of science as a discipline will require teachers to adopt new approaches to instruction (Bybee, 2014; NRC, 2012). Teachers, as a result, must make choices about what to emphasize inside the classroom and what type of instructional materials or approaches to use to support student learning, and these decisions will have a major influence on what students do inside the classroom (Barton, 2003; Pimentel & McNeill, 2013; Prime & Miranda, 2006). In this study, Helen and Willa enacted an instructional model that featured broad engagement in scientific practices. It is likely, however, that many teachers may face challenges with such instruction and may lack the background experiences to successfully emphasize science practices in their classroom (Pruitt, 2014). It is clear that teachers play a crucial role in this type of instruction (Bybee, 2014); therefore, future studies should investigate the specific teacher actions and scaffolds used by teachers when they engage their students in science practices. Additionally, understanding the background experiences teachers bring to the teaching context, such as their pedagogical content knowledge related to incorporating specific science practices (McNeill, Gonzalez-Howard, Katsh-Singer, & Loper, 2015), will inform the nature of support that teachers need to establish classroom environments that promote student learning through engagement in scientific practices.

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Strategies Toward the Inclusion of Environmental Education in Educator Preparation Programs: Results from a National Survey

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A national study was conducted to investigate the inclusion of environmental education (EE) into educator preparation programs across the United States. Responses from teacher educators in institutions of higher education indicated that the infusion of EE into educator preparation programs is limited and varies greatly across the nation. Findings also identified more barriers than supports for the inclusion of EE, and there exists minimal knowledge and use of the North American Association for Environmental Education Guidelines for the Preparation and Professional Development of Environmental Educators by teacher educators for programmatic development and assessment. The results also indicated that most state licensure programs have few or no requirements related to environmental education, and in the majority of educator preparation programs, environmental education is not institutionalized.

A goal of environmental education (EE) is to develop a world citizenry that has the "knowledge, skills, attitudes, motivations, and commitment to work individually and collectively toward solutions of current problems and the prevention of new ones" (UNESCO-UNEP, 1976, p. 3). Through the years, this goal has led to an increased emphasis on the inclusion of EE in formal education and, consequently, an increasing need for effective EE teachers (McDonald & Dominguez, 2010; Moseley, Desjean-Perrotta, & Crim, 2014). Emphasis on the inclusion of EE curricula and teaching strategies in educator preparation programs (EPPs) is essential (Cutter-Mackenzie & Smith, 2003; McKeown-Ice, 2000; Tuncer et al., 2009).

The importance of EE in teacher education has been well established globally for over four decades. International support for including EE in teacher education can be traced back to the Belgrade Charter (UNESCO-UNEP, 1976) and the Tbilisi Declaration (UNESCO-UNEP, 1978). Almost three decades ago, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) described the preparation of environmentally literate teachers as a top priority (UNESCO-UNEP, 1990). In 2002, the United Nations General Assembly declared the time period between 2005 and 2014 as the Decade of Education for Sustainable Development (DESD) in order to emphasize the critical role of education and teachers in moving toward a more sustainable world. In addition, the UNESCO World Conference on Education for Sustainable Development (2009) called for efforts to integrate EE into both preservice and inservice programs.

Rationale for the Study

Research shows that classroom teachers are a strong influence on how children perceive their role in the environment (Rickinson, 2001; Shepardson, Wee, Priddy, & Harbor, 2005) and play a critical role in advancing environmental literacy in schools (Álvarez-García, Sureda-Negre, & Comas-Forgas, 2015; Hestness, McGinnis, Riedinger, & Marbach-Ad, 2011; Karpudewan & Ismail, 2012). However, previous studies indicate that preservice teachers often have limited environmental knowledge (Puk & Stibbards, 2010; Tuncer, Boone, Tuzun & Oztekin, 2014) and hold misconceptions about the environment and environmental issues (Khalid, 2003). For example, in several prior studies, preservice teachers held the misconceptions that holes in the ozone layer are a direct cause of global warming (Summers, Kruger, Childs, & Mant, 2000), ozone layer depletion is directly related to the greenhouse effect (Michail, Stamou, & Stamou, 2007), and pollutant gases are responsible for creating the greenhouse effect (Boon, 2010). These misconceptions may exist because of the complex and abstract nature of the concepts, the misrepresentation of these issues in the media, or inaccuracies in textbooks (McDonald & Dominguez, 2010).

Additionally, research in science education indicates that teachers who hold negative attitudes toward science have a greater tendency to pass these attitudes on to their students (Osborne, Simon, & Collins, 2003). We believe the same potential exists for teachers in relaying negative attitudes about the environment to their students. There exists a growing body of literature that indicates pro-environmental

behavior is a function of environmental literacy and may be learned through increased environmental knowledge (Peer, Goldman, & Yavetz, 2007). Likewise, previous studies indicate a correlation of environmental knowledge to positive environmental attitude (Tikka, Kuitunen, & Tynys, 2000) and an association between attitude and behavior (Hsu, 2004). Individuals may change their environmental behavior when their attitudes and beliefs change (Dietz, Fitzgerald, & Shwom, 2005), potentially resulting in increased environmental literacy.

Teachers' attitudes strongly influence their classroom practice and content (Sund & Wickman, 2008) as they are more likely to teach material in which they are interested and knowledgeable (Haney & McArthur, 2002; Roehrig & Kruse, 2005). Because the classroom teacher is one of the primary environmental educators for children, it is critical that EPPs prepare preservice teachers to effectively teach EE (Rickinson, 2001). Champeau (1990) found in his study that preservice teachers who receive training in EE during their EPPs are more likely to incorporate EE into their teaching. However, a meta-analysis of research studies in EE concluded that preservice teachers, despite having positive attitudes toward EE, acquire limited environmental knowledge during their higher education training (Álvarez-García et al., 2015). Teacher educators can assist preservice teachers in understanding how their attitudes toward and knowledge about the environment influence their future teaching, exponentially impacting the environmental literacy of the children in their future classrooms (Powers, 2004).

Insufficient teacher preparation in EE has been identified in previous studies as a limitation in past EE efforts (Álvarez-García et al., 2015; Quinn, Littledyke, Taylor, & Davis, 2010). However, previous studies identified several challenges that need to be addressed by EEPs related to EE in teacher preparation programs. These included lack of time for preparation and implementation (Paige, Lloyd, & Chartres, 2008), multiple priorities competing for time and attention (Moore, 2005), lack of communication among subject areas (Littledyke, Taylor, & Eames, 2009), lack of content, pedagogical knowledge, and skills in teaching in outdoor settings (Kim & Fortner, 2006). Other studies identified other challenges such as overcrowding of the curriculum (Pearson, Honeywood, & O'Toole, 2005) and the lack of resources and marginalization of EE in education (Summers, Childs, & Corney, 2005). Despite these challenges, EPPs have the potential to bring about significant change through the education of new teachers and professional development for practicing teachers in EE (UNESCO, 2012).

In response to the challenges identified above, the North American Association for Environmental Education (NAAEE) developed a set of national recommendations regarding the basic knowledge and skills educators need in order to provide high-quality EE. The *Guidelines for the Preparation and Professional Development of Environmental Educators* are designed to be applied: (a) within the context of EPPs; (b) to the professional development of educators in both formal and nonformal educational settings; and (c) to all educators who are responsible for the integration of EE into curricula and programs (NAAEE, 2004). The underlying assumption of the *Guidelines* is that teachers should have a working knowledge of what comprises environmental literacy and a clear understanding of how this knowledge can impact environmentally sound behaviors.

Disinger and Roth (1992) defined environmental literacy as "the capacity to perceive and interpret the relative health of environmental systems and take appropriate action to maintain, restore or improve the health of those systems" (p. 2). The NAAEE *Guidelines* (2004) further states that environmental literacy depends on the learner's ability to question, analyze, and interpret environmental issues; understand the processes and systems that make up the environment; and define, learn about, evaluate, and act on environmental issues, taking personal and civic responsibility. More recently, the *Framework for Assessing Environmental Literacy* (Hollweg et al., 2011) defines "an environmentally literate person as someone who, both individually and together with others, makes informed decisions concerning the environment; is willing to act on these decisions to improve the well-being of other individuals, societies, and the global environment; and participates in civic life" (p. 2). Accordingly, the NAAEE *Guidelines* describes an environmentally literate citizenry as individuals who understand and think in terms of systems and are capable of making well-informed decisions rooted in the belief that "humans can live with nature and act equitably toward each other" (p. 2).

To further address the issue of teacher competency in environmental literacy, the NAAEE established the Preservice Teacher Advisory Council within its organization whose primary focus is the preparation of future teachers in EE. With support from the Council, a national research study was developed to investigate the current state of inclusion of EE into EPPs across the United States. This national study expands upon prior studies conducted over a decade ago (Heimlich, Braus, Olivolo, McKeown-Ice, & Barringer-Smith, 2004; Mastrilli, Johnson, & McDonald, 2001; McKeown-Ice, 2000) which reported the following limitations regarding the inclusion of EE in EPPs: (a) few EPPs had institutionalized EE into their curriculum frameworks, (b) EEPs varied greatly across the United States,

and (c) preservice teachers were not receiving the education necessary to effectively teach EE in preK–12 schools.

Research Questions

Because of the importance of including EE in schools, the need to adequately prepare teachers to teach about the environment, and the challenges of implementing EE into teacher education, the purpose of this national study was to address the following broad question: *How are preservice teachers in the United States being prepared to teach primary and secondary students about the environment?* In keeping with this purpose, we developed the Environmental Education Teacher Preparation Survey (EETPS). This survey explored the extent to which the NAAEE *Guidelines* have been integrated into programmatic decisions and practice, the factors that serve as supports or barriers to including EE in EPPs, and the EE resources being used. The format of the survey instrument contained items designed to specifically address five guiding research questions (RQ):

- RQ1: How is environmental education included in educator preparation programs across the United States?
- RQ 2: What are the supports and barriers toward the inclusion of environmental education into educator preparation programs?
- RQ3: How are the NAAEE *Guidelines* implemented in educator preparation programs?
- RQ4: What are teacher educators' perceptions about the effectiveness of educator preparation programs in preparing preservice teachers in EE?
- RQ5: What EE resources are used in educator preparation programs?

Methodology

The EETPS consists of six parts designed to address the five research questions. Part I summarizes the intent of the research and solicits consent to participate in the study. Basic demographic information about participants and institutions is requested. Part II explores basic programmatic structures and requirements of EE within the EPPs, including state licensure options, course requirements, and degree options available (RQ1). Part III focuses on supports and barriers related to incorporating EE into EPPs (RQ2), and Part IV assesses teacher educators' familiarity with the *Guidelines* and the role of the *Guidelines* in program development and assessment (RQ3). In Part V, participants self-reported on their perceptions of their EPPs' effectiveness in EE preparation (RQ4), and in Part VI, they identified supporting EE resources and opportunities provided to preservice teachers in their programs (RQ5).

Data Collection

Descriptive research methodology was used to obtain a description of characteristics of current EPPs as reported in survey responses. As explained by Jackson (2011), surveys can be successfully used in research when "questioning individuals on a topic or topics and then describing their response" (p. 17). The survey responses were collected and aggregated by institution and disaggregated for each research question.

Contacts within higher education institutions affiliated with an educator preparation program were obtained from the North American Association for Environmental Education (NAAEE) and the Council for the Accreditation of Educator Preparation (CAEP). The lists of contacts from the two organizations were sorted by institution and duplicates were eliminated. The invitation to complete the survey was initially emailed to 748 institutional contacts from across the United States. A second invitation was emailed to all contacts a month later.

Section I of the survey reported responses from 211 institutions of higher education in 37 states, Washington, DC, and Puerto Rico, indicating a 28% return rate (211 responses out of 748 contacts). Results indicated that 62% of the respondents were from public and 38% from private institutions of higher education. Responses came from institutions that reported multiple degree and program types that lead toward teacher certification: 86% of the responding institutions offer four-year undergraduate programs (baccalaureate degree), 40% have post baccalaureate programs (non-degree; licensure only), and 49% grant graduate degrees (master and/or doctoral programs).

According to Nulty (2008), online surveys have an average response rate 23% lower than paper-based surveys. The paper-based EE survey conducted by McKeown-Ice (2000) had a response rate of approximately 62%. We acknowledge that our data set ($n = 211$) with a response rate of 28% (lower rate than the comparable McKeown-Ice study) could potentially contribute to a limitation to our findings. However, we ascertain that our response rate adequately represents a national probability sample of EPPs for an online survey in that we received responses from 211 institutions, representing 37 states and 2 territories. We attribute the lower response rate due to the time at which the survey was administered. Initial surveys were emailed to contacts in June with the follow-up email sent in late July when some institutions of higher education are not in session.

Study Context

Because teacher education in the United States is decentralized, classroom teachers must be licensed by the state in which they teach. Regarding the discipline of EE,

only four out of 50 states (Wisconsin, Pennsylvania, Kentucky, and Washington) have standards or licensure requirements related to EE in teacher education (Simmons, 2014). Recognizing the importance of including EE in teacher education, the NAAEE established the *Guidelines for the Preparation and Professional Development of Environmental Educators* (NAAEE, 2004). These *Guidelines* provides recommendations about the basic knowledge and skills that both formal and nonformal educators need in order to provide effective EE instruction.

Survey Development

Following standard measurement criteria for developing valid measures, the items on the EETPS were subjected to multiple cycles of development, reviews, and revision. Content and construct validity of the survey were achieved through a review process involving three validity panels and a focus group of experts in EE and teacher education. The research team for this study was comprised of three university teacher educators with expertise in EE knowledge, research, and pedagogy. The EETPS was developed for this study through modification of items on previous national surveys relating to EE (Heimlich et al., 2004; McKeown-Ice, 2000) and development of new items through examination of the literature related to EE and the NAAEE *Guidelines*. Specifically, the instrument development process involved the use of expert feedback with respect to content addressed and language of items within the survey.

The first draft of the survey, developed by the research team, was initially reviewed by a panel of nine members of the NAAEE Preservice Advisory Council. This panel of teacher educators with expertise in EE examined the survey draft for content accuracy, clarity, and representativeness of items. Feedback from this panel was used to revise the first draft of the survey.

Next, a focus group of 20 members of the NAAEE Preservice Advisory Council was administered the revised survey (Draft 2) at an annual meeting of NAAEE. Focus group members were asked to provide oral feedback about the clarity of instructions; wording of items; time devoted to completing the survey; and response format, length, and content. The research questions of the study were revisited, and the feedback obtained from this discussion resulted in additional revisions to the instrument (Draft 3).

Draft 3 of the survey was then sent for additional review by a second panel of two content experts in EE with extensive knowledge of the NAAEE *Guidelines*. Based upon their feedback, the survey was again revised (Draft 4). While Drafts 1, 2, and 3 were emailed to reviewers as Word documents, Draft 4 was loaded into an electronic medium and field tested with a third panel of two experts in teacher education with limited expertise in EE for technical components, language congruency, sentence construction, and word usage. Panel members were given a link to an online survey, which the authors created using SurveyMonkey (2012) (http://www.surveymonkey.com). They identified areas where content assumptions or technology uses existed or terminology was ambiguous or confusing. This feedback was used to revise and finalize the EETPS.

Data Analysis

All responses from the EETPS were compiled in the SurveyMonkey platform. Using descriptive statistics, data collected from the survey were analyzed using a frequency distribution analysis of individual survey questions and expressed primarily as percentages. The survey consisted of six response options that varied based on the nature of the questions. These included (a) yes/no responses, (b) short answers, (c) check all that apply indicators, (d) multiple choice selections, (e) Likert scale ratings, and (f) multiple choice matrices. There were also opportunities for optional open ended responses in each section. Because these responses corroborated or slightly elaborated upon the answers to the closed questions, they were not coded but rather used to support survey question data and reported as direct quotes from respondents (Thomas, McColl, Priest, & Bond, 1996). Not all respondents addressed every question in the survey; data reported for each question indicate the number of responses for that particular survey item.

Results and Discussion

Research Question 1 – Inclusion of EE

Part II of the survey explored the components of state licensure options, course requirements, and degree options included in the EPPs. Less than 15% of the respondents reported that their states offer some form of teacher licensure in EE: initial teacher licensure, 4%; endorsement, 11%; certificate (non-teaching), 13%; advanced certification, 1% (graduate level) (see Table 1). These state licensure options are those used by CAEP for national

Table 1
State Credential Options in Environmental Education (n = 115)

	Yes % (*n*)	No % (*n*)	Do Not Know % (*n*)
Initial Certification	4% (5)	70% (79)	26% (29)
Endorsement	11% (12)	57% (65)	33% (37)
Certificate	13% (15)	53% (60)	34% (39)
Advanced	1% (1)	60% (68)	39% (44)

Table 2
 # Students in the Teacher Education Program Required to Take One or More Separate Courses in Environmental Education (n = 107)

	Yes % (*n*)	No % (*n*)	Do Not Know % (*n*)
Early childhood	7% (7)	86% (86)	7% (7)
Elementary	12% (2)	81% (83)	7% (7)
Middle	7% (7)	86% (83)	7% (7)
Secondary	10% (10)	82% (84)	6% (7)
All level	2% (2)	87% (82)	11% (10)

accreditation of EPPs. Due to the nonexistence of a teacher licensure or endorsement program in EE at the institutional level, 70% of the respondents indicated their institutions do not recommend students for state teaching licensure in EE, and 57% of the programs do not recommend students for endorsements in EE.

Less than 15% of the responses indicated that preservice teachers are required to take a specific course in EE, regardless of licensure levels (early childhood, 7%; elementary, 12%; mid-level, 7%; secondary, 10%; all level, 2%) (see Table 2). However, as reported in the survey, EE content is partially embedded into other courses within existing curricula for teacher education, occurring most frequently at the elementary licensure level (52%) (see Table 3). According to one respondent: "EE is basically embedded into one required science course, the elementary methods in math and science and with content area literacy in secondary ed. However, it probably gets more exposure through the local, regional, and state media as news breaks about drought, use of water, wind, heat, etc."

Research Question 2 – Supports and Barriers

When identifying supports and barriers for including EE in their EPPs, participants were asked to rank provided factors on a 5-point Likert scale ranging from strong barrier (1) to strong support (5). Aggregate percentages reflect how each factor was perceived by respondents across the response options. While separated in Table 4, data are combined in the article discussion by clustering Major Support with Minor Support and Major Barrier with Minor Barrier. Overall, more barriers than supports were indicated for including EE in EPPs (see Table 4).

Table 3
Programs with EE Content Partially Embedded into Teacher Education Coursework (n = 105)

	Yes % (*n*)	No % (*n*)	Do Not Know % (*n*)
Early childhood	39% (35)	46% (41)	15% (13)
Elementary	52% (49)	37% (35)	11% (10)
Middle	38% (29)	47% (36)	16% (12)
Secondary	44% (39)	42% (37)	14% (12)
All levels	10% (6)	63% (38)	27% (16)

One of the strongest supports reported was collaboration between teacher education departments and informal education sites that are proponents of EE (43%) such as local parks and nature centers. The survey results also indicated that more than one third of the respondents (41%) recognized that student interest has the potential as a support. Students can provide the catalyst for initiating an EE program at their institutions. Another support reported includes the diversity and availability of EE activity guides, curricula, and general resources for the use in curriculum planning and teaching (41%). In addition, an institutional mission that includes issues of environmental responsibility was cited by some survey respondents (35%) as being an important factor that supports the systematic integration of EE. When identifying the perceived barriers to including EE in the teacher preparation programs, 80% of the respondents indicated that allocated course time, or lack thereof, was a barrier. Other barriers that were identified included the lack of: (a) funding for an EE program (67%); (b) state teaching certification or degree requirements in EE (53%); (c) faculty interest in EE (53%); and (d) a systematic approach involving all stakeholders in infusing EE into the teacher preparation program (52%).

While supports were evident, the data from this survey suggest there are more perceived barriers than supports for the inclusion of EE in EPPs across the country. One respondent summed up barriers at his/her institution to be: "[Lack of] budgetary resources, released time, commitment of fiscal and programmatic support at the university level." Over half of the respondents (54%) identified that their state licensure guidelines (or lack of) is a major barrier for including EE in EPPs.

Research Question 3 – Familiarity and Implementation of EE Guidelines

When questioned regarding familiarity with the NAAEE *Guidelines*, 43% of the respondents indicated they had never heard of them, 32% were somewhat familiar with them, and 24% were very familiar (see Table 5). As one respondent indicated: "Never heard of EE standards. As I read them I realized we nonetheless do these things as good overall educators." When asked about the extent to which the *Guidelines* were integrated into their EPPs, 6% fully integrate them for program development, and 3% fully integrate the *Guidelines* for programmatic assessment (see Table 6).

Table 4
Supports and Barriers to Including EE in Educator Preparation Programs (n = 94)

	Major Barrier % (*n*)	Minor Barrier % (*n*)	Neither % (*n*)	Minor Support % (*n*)	Major Support % (*n*)
Collaboration between teacher education department and non-formal education agencies and organizations relevant to EE	4% (4)	10% (9)	44% (40)	21% (19)	22% (20)
Student interest in EE	9% (8)	15% (14)	36% (34)	32% (30)	9% (8)
Availability of EE activity guides, curricula and general resources for planning	2% (2)	17% (16)	40% (37)	21% (19)	20% (18)
Institutional vision/mission	12% (11)	23% (21)	31% (29)	26% (24)	9% (8)
Collaboration between teacher education and other departments	6% (5)	19% (17)	42% (38)	22% (20)	12% (11)
Access to substantive, up-to-date EE resources	4% (4)	27% (25)	42% (39)	15% (14)	11% (10)
Professional association guidelines and standards	10% (9)	17% (16)	39% (36)	24% (22)	10% (9)
Administrative support in EE	20% (18)	22% (20)	42% (39)	9% (8)	8% (7)
Educators' knowledge related to the environment and environmental issues	20% (18)	27% (25)	20% (18)	16% (15)	17% (16)
Educators' preparation time	22% (20)	29% (27)	41% (38)	5% (5)	3% (3)
Educators' knowledge of EE methods	24% (22)	27% (25)	22% (20)	14% (13)	14% (13)
Educators' interest in EE	20% (18)	34% (31)	23% (21)	11% (10)	13% (12)
A systematic approach (all stakeholders) to infuse EE	30% (27)	22% (20)	34% (31)	11% (10)	3% (3)
State certification guidelines	34% (31)	20% (18)	35% (32)	8% (7)	4% (4)
Funding	38% (35)	29% (27)	29% (27)	4% (4)	0% (0)
Allocated course time	57% (52)	23% (21)	12% (11)	1% (1)	7% (6)

Research Question 4 – Effectiveness of Preparation

When respondents were asked to self-report how they perceived the effectiveness of their overall EPP in preparing preservice teachers to teach EE (see Table 7), less than 10% stated their programs were *Very Effective* and less than 15% identified *Moderately Effective*. When asked how they perceived the effectiveness of their educator preparation program based on six listed factors of preparation, "Conveying environmental action strategies related to EE" ranked the highest for *Not at all Effective* (51%), and "Identifying local resources for EE" was ranked the highest for *Very Effective* (11%).

Research Question 5 – EE Resources

Given a list of EE resources as recommended by members of the NAAEE Preservice Advisory Council, participants were asked to indicate if each resource was *Not Used, Referenced, Integrated, or Do Not Know* (see Table 8). Overall, two-thirds of the listed resources were identified as *Not Used* or *Do Not Know*. "State or Government publications" were most often *Referenced* (28%) while "Local or regional materials and resources" were most often *Integrated* (36%) into the curriculum in EPPs. Considering international/national curricula, Project WET (33%), Project WILD (34%), and Project Learning Tree (PLT) (35%) were reported as the most often integrated resources; yet, one-fifth of the respondents reported that they *Did Not Use* or *Did Not Know* these EE resources. Additionally, 14 respondents listed several other resources that included Fish Banks, Investigating and Evaluating Environmental Issues and Actions (IEEIA), Energy Smart, Earth Gauge, and Lester Brown's Plan B.

Table 5
Extent of Familiarity with Guidelines for Preparation and Professional Development of Environmental Educator (NAAEE, 2004) (n = 99)

	Never Heard of Them % (*n*)	Somewhat Familiar % (*n*)	Very Familiar % (*n*)
You are familiar with the *Guidelines*	43% (43)	32% (32)	24% (24)

Table 6
Extent of Integration of Guidelines for Preparation and Professional Development of Environmental Educator (NAAEE, 2004) (n = 99)

	Do Not Integrate % (*n*)	Somewhat Integrate % (*n*)	Fully Integrate % (*n*)
Programmatic development	62% (59)	32% (31)	6% (6)
Programmatic assessment	68% (64)	30% (28)	3% (3)

Table 7
Effectiveness of Teacher Preparation Program (n = 88)

	Not at All % (*n*)	Somewhat % (*n*)	Moderately % (*n*)	Very % (*n*)
Conveying environmental content knowledge	31% (28)	47% (43)	13% (12)	9% (8)
Conveying instructional methods related to EE	34% (30)	41% (37)	15% (14)	10% (9)
Educating about environmental issues	25% (21)	52% (47)	14% (13)	11% (9)
Graduating students with a basic level of environmental literacy	34% (30)	49% (44)	8% (7)	9% (8)
Conveying environmental action strategies related to EE	51% (46)	33% (30)	19% (9)	6% (6)
Identifying local resources for EE	30% (27)	42% (37)	16% (15)	11% (10)
Effectiveness of EE preparation overall	35% (31)	50% (44)	8% (7)	7% (6)

Discussion

Thirty years ago, Wilke (1985) reported that "teacher education programs in environmental education remain relatively scarce and poorly developed" (p. 1). Despite research studies indicating that EE can provide positive student outcomes in academic achievement, critical thinking, motivation, and engagement (Knapp & Benton, 2006; Smith-Sebasto & Semrau, 2004; Stern, Powell, & Ardoin, 2008), our survey results indicate that preservice teachers receive limited exposure to EE in their teacher preparation programs. These results mirror results from earlier studies completed by McKeown-Ice (2000), Lane, Wilke, Champeau, and Sivek (1994), and Smith-Sebasto and Smith (1997). In fact, the responses for overall effectiveness in this survey indicated over 75% of the respondents rated their programs as *Not at all Effective* or *Somewhat Effective*, while the study done by McKeown-Ice stated 66% of the respondents rated their programs poor or adequate.

There still exist a limited number of states that offer teacher licensure in EE. Consequently, few universities require specific coursework or competencies in EE. As a result, the implementation of EE in teacher education across the nation is: (a) generally not institutionalized or systematic, (b) varies across programs and states, (c) tends to be in more elementary than secondary education programs, and (d) if present, is typically most often infused into existing science methods courses (Mastrilli, 2005; Powers, 2004; Simmons, 2014). If EE was identified in the survey as a component of an EPP, the level and design of implementation varied greatly across the nation. As one respondent lamented, "I wish we could do more. As it is, I sneak EE in my courses."

EPPs are mandated by state legislatures to include specific content and pedagogical courses, oftentimes within a limited number of total credit hours. Eighty percent of the survey respondents indicated that state requirements leave

Table 8
EE Resources (n = 79)

	Not Used % (*n*)	Referenced % (*n*)	Integrated % (*n*)	Do Not Know % (*n*)
Early childhood PLT	41% (37)	13% (10)	14% (11)	37% (29)
Environmental issues forums	53% (42)	9% (7)	11% (9)	37% (29)
Facing the future	40% (36)	18% (14)	9% (7)	38% (30)
Growing up WILD	36% (28)	22% (17)	16% (13)	38% (30)
Issue investigation and evaluation	36% (28)	24% (19)	23% (18)	27% (22)
Env. issues	41% (37)	15% (12)	8% (10)	34% (27)
Local or regional materials and resources	24% (19)	21% (16)	39% (31)	25% (20)
Nature scope	39% (31)	21% (16)	10% (8)	37% (29)
Project learning tree	24% (19)	25% (20)	38% (30)	23% (18)
Project WET	23% (18)	27% (22)	37% (29)	25% (20)
Project WILD	22% (17)	32% (25)	38% (30)	22% (17)
Think earth	57% (45)	8% (6)	3% (2)	43% (34)
World Watch Institute	49% (39)	16% (13)	6% (5)	38% (30)
Zero population growth	42% (33)	16% (13)	14% (11)	38% (30)
State or government	25% (20)	28% (23)	22% (17)	27% (22)

little to no room for support or elective courses such as EE in degree plans. As indicated by one respondent: "Given state DOE [Department of Education] and NCATE accreditation course requirements, there is no longer any room to require EE coursework in our teacher prep programs. Instead, mandated courses such as reading and ESL [English as Second Language] have replaced EE courses."

The findings in this study suggest that EE is not recognized as a discipline. This lack of recognition indirectly provides a barrier as compared to other disciplines that do require state licensure. As stated by one respondent: "EE is not listed in the state standards and thus we do not need to offer EE as a part of our program for all students." This could account for 52% of the survey respondents identifying a lack of a systematic approach as a barrier for infusing EE into their EPPs. This response supports existing literature that suggests a systematic approach at a university-wide level is required to impact change at the departmental and/or program level (Ferreira, Ryan, & Tilbury, 2006). According to one respondent: "We have no systematic attention to EE and faculty are pulled in many ways to focus content on legislated requirements for teacher preparation (e.g., civic and local government, technology, assessment)." As expressed by another respondent: "We just do not have a systematic approach. I believe we have the resources, but there are so many other standards and requirements bearing down on programs that we find it difficult to integrate everything into a compressed curriculum."

According to Greenwood (2010), "It is possible to work within the state-regulated system to create change, but first individuals and groups need to build relationships, demonstrate credibility, and then respond strategically to whatever openings exist" (p. 151). Systemic change may occur if committed teacher educators knowledgeable in EE engage in the development of strong partnerships and collaborations with other educators in teacher education and across campus, practicing teachers, nonformal educators, and policy makers. These partnerships can help broaden preservice teachers' knowledge about local resources and work with state teacher licensure agencies toward the inclusion of EE in teacher education.

Plevyak, Bendixen-Noe, Henderson, Roth, and Wilke (2001) wrote that "due to the interdisciplinary nature of EE, including environmental education in preservice teacher preparation programs is a challenging task" (p. 28). This challenge still exists today for the integration of the concepts and perspectives from the sciences with those from the social sciences in addressing solutions to environmental problems. Jaritz (1996) also recognizes this existing dichotomy where "isolated approaches to environmental education, which are tailored to the purposes of particular subjects, make it extremely difficult to prepare future teachers for their task to realize environmental education in an inter-disciplinary context" (p. 61). However, according to our survey, this seems to be the most frequent strategy for infusing EE into the teacher preparation programs, with the elementary science methods course as the course targeted the most:

Almost two decades ago, McKeown-Ice (2000) recommended that national standards or guidelines for the preparation of preservice teachers in EE should be developed. As a consequence, the NAAEE *Guidelines for the Preparation and Professional Development of Environmental Educators* now exist. However, despite the existence of these national *Guidelines* for over a decade, few teacher educators are aware of them and/or do not use them for program development or assessment. Teacher educators should consider incorporating the *Guidelines* into their programs and course work for this purpose.

We consider the lack of familiarity with the NAAEE *Guidelines* to be an indirect barrier to the inclusion of EE in EPPs. The *Guidelines* provide the competencies, background, resources, and information necessary for teacher educators preparing environmental educators. The fact that almost half of the respondents were not familiar with these national standards is cause for concern. One of the goals of NAAEE is to effectively disseminate information about the *Guidelines* nationally, and in order to do so, members of NAAEE provide training across the country. The results of this survey indicate that a renewed focus on familiarizing teacher educators with the *Guidelines* is needed. In addition, further research is needed regarding the impact of the integration of the *Guidelines* into an EPP on preservice teachers' attitudes about and knowledge of the environment.

While it is encouraging to see that some EPPs are utilizing specific resources, it is problematic that easily accessible EE resources and materials are not being utilized by many of the respondents. The list provided in the survey included 16 known EE resources in the field, as recommended by experts in EE and determined through the survey development process. Given that each of the 16 options listed was integrated by at least one respondent and respondents added only a few additional resources to the list, we feel the list was reflective of the most frequently used EE resources available to teachers. Established EE curricula should be introduced to preservice teachers across their program of study. These curricula can be integrated

into existing teacher education courses as examples of the integration of subject areas and inquiry-based instruction that promote active learning.

An emphasis on student-led campus and community projects is another way to integrate EE into existing curricula because students generally focus on local problem-solving situations (Krizek, Newport, White, & Townsend, 2012). Studies now show that two-thirds of prospective college freshmen look at campus green rankings as a factor in college choice (Pryor, Hurtado, Saenz, Santos, & Korn, 2007). However, to ensure sustainability, the infusion of EE into an EPP needs to go beyond ad hoc activities such as a campus wide recycling program and be recognized as an important component across curriculum, research, service, operations, and campus life (Ferrer-Balas et al., 2008; Krizek et al., 2012; Velazquez, Munguia, & Sanchez, 2005).

Our survey results indicate more needs to be done in preparing future teachers for the responsibility of developing environmentally literate citizens. The work by Plevyak et al. (2001) suggests that "successful implementation of EE includes teacher preparation" (p. 36), and our survey results indicate more still needs to be done in preparing future teachers for the responsibility of developing environmentally literate citizens. We believe a critical step at reaching environmental literacy for all is to equip preservice teachers with the necessary skills, knowledge, attitudes, and concern of environmental issues that would enable them to implement EE in their future classrooms. To enhance future teachers' EE competencies, EPPs must include the systematic implementation of EE (Van Petegem, Blieck, & Boeve-De Pauw, 2007) and integrate EE as a part of their programs and curricula rather than an occasional add-on (Heimlich et al., 2004).

Yavetz, Goldman, and Peíer (2014) argue that "all student teachers should receive appropriate preparation in this field... EE [should] not be limited to science disciplines; rather it should be included in all teacher education programs" (p. 370). Preservice teachers should be provided with opportunities to learn and practice effective instructional strategies on how to share these experiences with children. We know educating children in classrooms will potentially increase the environmental literacy of all citizens. To foster the development of these environmentally literate citizens, we need appropriately prepared teachers. This preparation must begin in the EPPs. As Ashmann and Franzen (2015) state:

> If teachers are not adequately prepared to teach our youth about the environment, then our hopes of the next generation being able to solve these problems has incurred a serious setback. Teachers who are well prepared to teach about the environment can have a lasting impression upon their students. (p. 2)

Recommendations

As researchers in EE, we have concluded from our own research with preservice teachers that many come to the university with simplistic perceptions of the environment (Moseley et al., 2014). These perceptions or beliefs may be founded and influenced in a number of ways as a result of an individual's education, the media, and personal, everyday lived experiences. We also recognize that behavior and perceptions can be difficult to change. Furthermore, we are aware of the research in teacher professional development that includes effective strategies such as structured and collaborative study groups, coaching, and immersion in inquiry (Boyle, While, & Boyle, 2004). However, these strategies can sometimes be difficult for EPPs to implement as a short-term intervention. Based on the results from this survey, we recommend that teacher educators, in promoting best practices in professional development, should form partnerships with informal EE organizations, capitalize on student interest, and utilize available EE curriculum materials.

The foundation of the EE program within our EPP rests on the belief that environmental knowledge alone is not sufficient. In order to bring about behavior change, preservice teachers also need to have a variety of experiences outdoors over time in order to become environmentally sensitive. In addition, they need opportunities within the higher education setting to engage in focused and reflective explorations of environmental issues. Our prior research suggests the majority of our teacher candidates continue to adhere to an object conception of the environment despite the increasing exposure to EE provided throughout their teacher preparation program (Moseley et al., 2014). Therefore, further research is needed to investigate which strategies are more effective in developing preservice teachers' environmental literacy and challenging their assumptions and beliefs. Determining effective ways on how to include an interdisciplinary approach to EE in programs that may conflict with state policies is another critical area needing further research.

Collectively, teacher educators need to provide a focused and consistent effort toward raising awareness of the critical need for EE in EPPs if any progress is going to be made in this area. EE needs to become an integral component of every EPP. As Papadimitrious (2004) states, "educating students

about such issues [like EE] is also a challenge for educators because the traditional didactic strategies are inappropriate and so new innovative instructional strategies and techniques should be invented which means that a vast area for research is opened" (p. 306). This applies to teacher educators as well.

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Examining Secondary Mathematics Teachers' Opportunities to Develop Mathematically in Professional Learning Communities

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To make progress toward ambitious and equitable goals for students' mathematical development, teachers need opportunities to develop specialized ways of knowing mathematics such as mathematical knowledge for teaching (MKT) for their work with students in the classroom. Professional learning communities (PLCs) are a common model used to support focused teacher collaboration and, in turn, foster teacher development, instructional improvement, and student outcomes. However, there is a lack of specificity in what is known about teachers' work in PLCs and what teachers can gain from those experiences, despite broad claims of their benefit. We discuss an investigation of the work of secondary mathematics teachers in PLCs at two high schools to describe and explicate possible opportunities for teachers to develop the mathematical knowledge needed for the work of teaching and the ways in which these opportunities may be pursued or hindered. The findings show that, without pointed focus on mathematical content, opportunities to develop MKT can be rare, even among mathematics teachers. Two detailed images of teacher discussion are shared to highlight these claims. This article contributes to the ongoing discussion about the affordances and limitations of PLCs for mathematics teachers, considerations for their use, and how they can be supported.

Recommendations for mathematics teacher professional development (PD) assert the need for a clear focus on teachers' mathematical content knowledge and its connection to the work of teaching, especially in the context of new standards and the resulting demands on teachers' work (Marrongelle, Sztajn, & Smith, 2013). An increasing number of schools and districts have worked to develop professional learning communities (PLCs) to support teacher development and promote instructional change and positive impacts on student achievement (Mindich & Lieberman, 2012). With PLCs, teachers are provided with time and other resources to collaboratively discuss instruction, common planning and assessment, and student data. While use of PLCs is in line with goals for ongoing, collaborative, and practice-based PD for teachers (Bausmith & Barry, 2011), the widespread use of PLCs is at a "crossroads" (Talbert, 2010) due to lack of clarity around their purpose and benefits and irregularity in their implementation.

In this article, we look at a part of that dilemma. Specifically, we question the extent to which teachers' work in PLCs—specifically when the PLCs are teacher-led and operate without researchers or skilled teacher leaders—reliably provides opportunities to develop mathematical knowledge. Attention to how teachers may develop their knowledge of the subject matter they teach is not regularly addressed in the literature on PLCs, despite broad claims of PLC's benefits on content knowledge (Bausmith & Barry, 2011). We present findings from a study investigating the ways in which opportunities emerged for secondary teachers in PLCs to develop "mathematical knowledge for teaching" (MKT; Ball, Thames, & Phelps, 2008). We highlight hurdles that limited these opportunities and propose that some of these hurdles may ultimately be limitations of the broad potential of PLCs that should be considered in practice.

Background on PLCs

Across an extensive body of research and literature reviews, such as those from Fulton, Doerr, and Britton (2010) as well as Vescio, Ross, and Adams (2008), PLCs are broadly defined as groups of teachers who meet regularly and over an extended time to focus on issues of student learning in local contexts. DuFour and his colleagues (DuFour, 2014; DuFour, DuFour, & Eaker, 2008)—whose ideas are commonly used to frame teacher collaboration in schools and districts—highlight a need for shared goals, vision, and values as well as an orientation focused on continuous improvement and student learning. Others such as McLaughlin and Talbert (2008) and Mindich and Lieberman (2012) similarly define PLCs, while also emphasizing the feature of shared or deprivatized practice by engaging in activities such as analyzing student work, designing and critiquing lessons and activities, and developing and examining data from common assessments to measure progress.

The scope of a PLC in terms of its participants varies across the literature. For example, PLCs may refer to a group of teachers focused on the same grade level or course

(Mindich & Lieberman, 2012). These groups may develop on their own or as part of a school-wide effort. PLCs may be comprised of teachers from across schools, with the support of researchers or other teacher leaders and as part of a larger PD effort (Brodie, 2014). A PLC may also refer to a whole school and other stakeholders (DuFour, 2014; DuFour et al., 2008). In our work, we focus on PLCs as small groups of teachers that interact around common courses that were organized as part of a district-wide effort to promote teacher collaboration and support broad impacts on teaching and learning. We discuss this context in more detail in a section that follows.

PLCs or other models of teacher community have been widely used as a feature in the design of mathematics PD and the impacts of these settings have been at the focus of research studies (Borko, Jacobs, Koellner, & Swackhamer, 2015; Brodie, 2014; van Es & Sherin, 2010). Across the body of work on PLCs, teachers' participation in these communities has been shown to have positive impacts on teachers' attitudes toward collaboration (Mindich & Lieberman, 2012); on teachers' mathematical content knowledge, specifically around students' thinking (Brodie, 2014; van Es & Sherin, 2010); and on students' achievement (DuFour, 2014). While the benefits of PLCs are wide-ranging and widely reported, they are often based in self-reports from practitioners with less known about how practices of teachers' collaboration in PLCs support particular gains (Bausmith & Barry, 2011).

Theoretical and Conceptual Framework

The idea of PLCs builds from the sociocultural lens of communities of practice (Wenger, 1998). Teaching is a cultural activity comprised of the understandings, tools, and activities shared by the collective of practitioners, making it less about what individual teachers do and more about meanings that are negotiated collectively (Lampert, 2010). As mathematics teachers collaborate while situated in authentic work and contexts, the shared knowledge, experiences, and other resources of the group support development. This conception of learning in, from, and for teaching positions PLCs as a potential vehicle for teacher development. This theoretical perspective also has implications on how knowledge—particularly the way one knows the content they teach—is defined and how such knowledge is developed.

Developing Teachers' MKT as a Goal for PD

While many studies and reports attribute participation in PLCs to the development of content knowledge, there is not consensus in what is meant by content knowledge nor how PLCs specifically support that development. Recent research on teacher PD (Borko et al., 2015; Elliott et al., 2009; Lesseig et al., 2016) addresses this problem by specifying MKT as the content knowledge goal for mathematics teachers. Ball and her colleagues (2008) describe MKT as the mathematical knowledge-in-action needed to carry out the mathematical work of teaching—including analyzing and modifying tasks, choosing appropriate examples, and evaluating the correctness of and reasoning underlying students' claims. While pedagogical skill is involved with these tasks, as well as knowledge of curriculum and students, teachers use their disciplinary knowledge in a way that is unique to the work of teaching, giving more specificity to the idea of "knowing mathematics deeply." The construct of MKT has continued to be developed (Hoover, Mosvold, Ball, & Lai, 2016) and instruments to measure MKT have been designed and tested (Kaarstein, 2014). MKT has been linked to quality of mathematics instruction (Hill, Umland, Litke, & Kapitula, 2012) and student achievement (Kersting, Givvin, Thompson, Santagata, & Stigler, 2012), thus warranting its position as an important and viable way to focus the otherwise vague consideration of teachers' mathematical content knowledge.

Due to the nature of MKT, it is not something learned in college mathematics courses (Youngs & Qian, 2013), nor is it developed or used in other professions (Suzuka et al., 2009). MKT is also not something teachers necessarily pick up in the context of their day-to-day work on the job. Efforts have been made to understand the contexts and supports that foster the development of MKT, including specialized tasks (Suzuka et al., 2009) and PD models that facilitate teachers' engagement with mathematics (Borko et al., 2015; Elliott et al., 2009). As a result, what it looks like to do mathematics with teachers should be different from students' work on mathematics in a classroom, resulting in a complex nature of teachers' collective work around mathematics (Elliott et al., 2009).

We take up these ideas from the literature and consider MKT to be a productive way to frame goals around teachers' mathematical development, including in discussions about PLCs. The work of Borko and her colleagues (2015) as well as others highlights the way in which teachers' MKT can be purposefully supported and developed in PLCs and other collaborative structures. These examples are powerful, but are insufficient as the only evidence to make claims about the benefits of all types of PLCs, even those that are comprised only of mathematics teachers but have different origins or supports.

Research Questions

With the study we describe in this article, we addressed a need to further understand the way in which the

collaborative structures of PLCs—as seen in a wider variety of uses and conceptualizations—may serve in the development of MKT or the additional supports and considerations that might be needed to support such specific goals. Further understanding of these opportunities and constraints add to a developing sense of how to structure, support, and rely on teacher collaboration in school-based sites as a form of professional development. In particular, we pursued the following questions through an investigation of the interactions of two teams of teachers operating as PLCs:

1. To what extent do teachers' discussions focus on mathematics content in PLCs?
2. How do teachers' ways of working and collaborating around mathematics-focused discussions foster or constrain opportunities to develop MKT?

Methods

Study Context

The study took place in a large, urban school district in the southeastern United States that implemented a particular model of PLCs from DuFour and colleagues (2008) to structure teacher collaboration. This effort was spurred by a local school and business consortium focused on improving high school graduation rates. At the time of the study, this effort was in its third year of implementation. In high schools, many teachers were organized in subject-specific teams to plan common lessons, investigate current issues, and evaluate and make decisions about their practice using student data. Each team assigned a teacher to serve as the leader, tasked with facilitating the group's meetings and attending monthly workshops with team leaders across the district. Based on research and other reports, such as that from Mindich and Lieberman (2012), this context of what PLCs come to mean in schools is common, thus making the investigation we report on here of broader importance.

A focus on two PLCs. Two teams of mathematics teachers participated in the study. Each team was housed at a separate, large high school in the district, what we will call Brantley High School and Elmwood High School (all school and teacher names used are pseudonyms). These two teams were chosen based on their response to a call for participants in a small study regarding the use of a PLC model in the district, with a focus on high school mathematics teachers. From the teams across the district that responded to this call, the teams from Brantley and Elmwood were chosen as the two that would be studied due, in part, to similarities between the teams and the schools. Both teams were organized to focus on Algebra I classes within their broader mathematics departments. The population at each school consisted of students from across the district, including students from the urban center of the district, resulting in socioeconomic and racial diversity in both schools. Each school's mathematics department was comprised of more than 15 teachers (split up across multiple PLC teams). Both schools implemented a late start one day per week to allow for weekly, 45-minute meetings for each PLC throughout the school year. All teachers in each group were expected to spend this time in their groups, although a variety of factors (including school related factors such as student organizations) would result in occasional absences.

This form of purposive sampling was a choice made by the researchers to limit some of the variation between the teams while potentially offering initial insight into similarities and differences of their collaborative practices. We did not make these choices to strive toward larger scale trends or unwarranted generalizations arising only from these two cases. Instead, we set out to construct images of these teams' collaborative practices as they pertain to mathematics and mathematics teaching. Furthermore, we aimed to construct those images with detail that allowed for the emergence of further questions and the consideration of these images in other contexts.

Brantley High School. The PLC that participated from Brantley High School consisted of five teachers—Hillary, Kate, Samantha, Luke, and Vincent. Four of the teachers (Hillary, Kate, Samantha, and Luke) had five or fewer years of teaching experience, and all five teachers had between two and four years of experience teaching Algebra I. Two of the teachers (Luke and Vincent) worked in other professions before starting their teaching career. Kate, Luke, and Samantha were part of the original Algebra I team at the school (in its third year), with Luke having served as the leader for the first two years. Hillary and Vincent were new to the team for the year of this study. Samantha assumed the role of team leader, selected by group consensus. As team leader, she was tasked with setting the agenda and moderating the group's talk and time. However, Luke continued to attend the district-wide Algebra I team leader meetings as he did during the previous year. This division of labor highlights the different ways in which a PLC like the ones highlighted in this article can be led. Furthermore, during this time, Kate was acting as the mathematics department chair, which brought a different leadership influence into the group.

Elmwood High School. The PLC that participated in the study from Elmwood High School consisted of four teachers—Jackie, Sabrina, Pam, and Doug. These teachers all taught an Algebra I course specifically serving students

who have previously taken and failed the course. Three of the four teachers (Jackie, Sabrina, and Doug) had taught for at least 10 years, although the team was newly organized around a focus on Algebra I. Two of the teachers (Jackie and Doug) had taught Algebra I for 13 years each but the other teachers were in their first year of teaching the course. Additionally, those teachers (Sabrina and Pam) were in their first year at Elmwood, having each previously taught at other schools. Jackie served as the team leader (and attended the district's Algebra I team leader meetings) and was also in the process of completing her administrative internship as part of a graduate program. Doug was in the early stages of taking coursework part-time as part of a doctoral degree program in mathematics education.

Data Collection

The primary data used to pursue our research questions were records of each team's interactions, specifically audio recordings of PLC team meetings and field notes completed by the first author. Over the course of the first semester of the school year, each team was observed four times during their regular weekly meeting time. Two of the observations of each team occurred in consecutive weeks to provide the opportunity to see teacher interactions in a sequence of meetings, with the other two observations spread over other times of the semester. The observations were non-participant in nature, with the observer not contributing to the discussions. We did not see the observer's presence at the meetings as a limitation in terms of how it may have affected the substance of the interactions observed. In part, this is because the teachers did not know in specific detail what the researcher was attending to in his observations.

The observer's field notes kept a record of attendance at meetings, seating arrangement, the general agenda and flow of the meeting, and any observations on teachers' interactions that would be relevant to the study. Due to this last point, some notes were more interpretive (e.g., noting agreement or conflict between teachers or noting potentially interesting mathematical moments or discussions). The field notes were reviewed with participating teachers individually as a form of member checking to ensure their validity relative to participants' perspectives.

Data Analysis

We conducted analyses in three steps: (1) annotation, (2) coding, and (3) interpretation. For annotation, the audio recordings were segmented into two-minute intervals. Within each interval, a written record was kept of the events of the meeting through a descriptive narrative including any notable direct quotes. Using these annotations as a basis, we applied two types of codes to each interval in pursuit of our first research question. First we coded each interval for the substance of the focus of the discussion (what we called "substance" codes; see Figure 1). Substance codes were developed in a collaborative and iterative process (Smagorinsky, 2008), starting with both authors collaboratively developing and applying a list of substance codes based on the annotations of one group meeting from each team. The first author then independently coded the remaining meeting annotations, keeping a record of new or revised codes and other notes (e.g., expanding or combining codes). Both authors revisited the coding and notes to come to agreement and resolve any issues.

Next we coded whether or not the topic of the discussion during each interval included focus on or reference to mathematics content (what we called the "math focus" code). We applied one of three codes to each interval: no mathematics, mathematics reference, and mathematics discussion. The "no mathematics" code was used when the interval involved no mention of specific mathematics topics or concepts. The "mathematics reference" code was used when specific mathematics topics or concepts were mentioned during the interval, although it was deemed to be in passing or only at a surface level. For example, when discussing an item on a shared assessment, teachers may have referred to the content of the item (e.g., scalar multiplication of matrices) and made a brief comment about the content (e.g., scalar multiplication of matrices seems to be easier for students than matrix subtraction; absolute value is no longer in the standards for the course). Finally the "mathematics discussion" code was used when there was interaction involving multiple people about specific mathematics content. From our data, these moments included discussions of where a particular topic should be in a sequence (and why) and how to teach a particular topic (and why). As with the substance codes, we applied "math focus" codes collaborative and individually, meeting to confirm consistency of coding and to address questions and resolve disagreements.

The final step of our analyses (i.e., "interpretation") supported our inquiry into our second research question and focused on the "mathematics discussions" of each group. For this, we started by taking the two-minute intervals coded as "mathematics discussion" and combining them with related, sequential intervals, forming what we called "instances." These instances captured complete segments of discussion in the PLCs that we felt were candidates for group interactions that could support the development of MKT. We collaboratively examined the audio records, and field notes from these instances to evaluate the way in which opportunities to develop MKT were fostered or

Substance Codes	Examples
Data analysis	• Discussion and analysis of assessment data • Analysis and interpretation of individual assessment item • Analysis of student strategies
Assessment design and logistics	• General discussion of design of assessments • Identifying specific items to include on/as assessments • Discussion of when to give various assessments, including common assessments from school or district • Discussion of use of pre-assessments and quizzes
Policies, norms, and procedures	• Discussion of expectations or policies around test and quiz retakes • Discussion of the assigning and/or grading of homework • Discussion of other grading procedures and policies
Unit and lesson planning	• Discussion of content standards • Sequencing of topics within and across units • Sharing curricular resources • Sharing instructional ideas and strategies, such as guided notes, procedures, technology activities, and approaches to teaching particular topics
Other	• Announcements • School logistics and issues • Student issues (e.g., attendance, behavior) • Group logistics, such as general agenda- and goal-setting

Figure 1. List of "substance" codes and examples of such discussion foci.

constrained and to describe the apparent factors and other themes influencing the work. We documented this collaborative interpretation through analytic notes, which were then used to look across all relevant instances to identify themes and trends.

Findings: Opportunities for Teachers' Mathematical Development During PLC Meetings

In this section, we address our two research questions, beginning with findings related to the mathematical focus of each team's discussion, then continuing with more detailed discussion of potential opportunities for teachers to develop MKT in the context of PLCs.

Research Question 1

Table 1 shows a breakdown of each team meeting in terms of total number of intervals and the number of intervals assigned each of the five substance codes. This breakdown shows how the focus changed across meetings and differed between the two teams. A striking trend was the extent to which the Elmwood PLC spent discussing topics we categorized as "other"—such as student issues and other broad school issues. When considering the general purposes of teacher collaboration in this district—planning common lessons, investigating current issues, and evaluating and making decisions about their practice using

Table 1
Inventory of Substance Codes Assigned to Meeting Intervals

Site and Meeting Number	Total Intervals	Data Analysis	Assessment Design and Logistics	Policies, Norms, and Procedures	Unit and Lesson Planning	Other
Brantley #1	23	6	6	6	3	2
Brantley #2	22	7	3	3	5	4
Brantley #3	23	5	5	0	6	7
Brantley #4	22	0	2	7	8	5
Elmwood #1	17	1	7	0	6	3
Elmwood #2	23	2	3	2	7	9
Elmwood #3	22	6	3	0	0	13
Elmwood #4	20	2	3	2	2	11

Table 2
Inventory of Meeting Intervals Organized by Substance and Math Focus Codes

Site and Math Focus Codes	Data Analysis	Assessment Design and Logistics	Policies, Norms, and Procedures	Unit and Lesson Planning	Other
Brantley (90 total intervals)					
No mathematics	6	13	16	5	18
Mathematics reference	10	3	0	10	0
Mathematics discussion	2	0	0	7	0
Elmwood (82 total intervals)					
No mathematics	4	14	4	5	36
Mathematics reference	4	2	0	2	0
Mathematics discussion	3	0	0	8	0

student data—it appears that these "other" topics were, in fact, off-topic.

Attention to these broad purposes for PLCs in the district also illuminated two other trends that show differences between these two teams. From the data in Table 1, as well as from the audio recordings and field notes, it was evident that the Brantley teachers were focused on the use of assessment data. The team spent a lot of their time analyzing data from shared assessments, talking about upcoming assessments (both design and logistics), and discussing policies and norms around topics such as grading. Conversely, the Elmwood teachers appeared to be more focused (when not discussing "other" topics) on sharing instructional ideas and common planning. In addition to the counts of coded intervals, Jackie's repeated reminders for teachers in the group to bring instructional ideas to share also signaled this apparent focus.

We were ultimately more interested in the extent to which each team's focus was on mathematics, although the substance codes allowed us to consider the types of PLC discussions provided the best opportunities for mathematical focus. Table 2 provides these data, considering the math focus of intervals across all of each team's meetings, broken down by substance code. Across both teams, discussion intervals coded as "policies, norms, and procedures" or as "other" did not include any mathematics reference or discussion and group discussions about "assessment design and logistics" only included occasional reference to mathematics. While these types of collaborative interactions may serve some need or goal (regarding PLCs or coming from the teachers themselves), they were not sites for developing MKT due to their lack of mathematical specificity.

The other two substance codes—"data analysis" and "unit and lesson planning"—provided the sites in which teachers' interactions were more focused on mathematics. For the Brantley PLC, a majority of the intervals coded as either "data analysis" or "unit and lesson planning" were also coded as "mathematics reference" or "mathematics discussion" (as opposed to "no mathematics"). Of those, many were coded as "mathematics reference," meaning the mathematics was mentioned more in passing. A recurring example of this was, in the context of looking at results from a common assessment, teachers would refer to prepared reports and not copies of students' actual work. Teachers would share brief observations or anecdotes about what item students answered incorrectly and general claims about what seemed to be the cause of the error. These comments were short and were not responded to directly by other teachers. The Elmwood PLC spent less of their time on data analysis or on unit and lesson planning although, when on those topics, the Elmwood teachers were more likely to have "mathematics discussions." The instances in which both groups were having "mathematics discussions" were of interest to better understand the nature of teachers' interactions in PLCs around mathematics and the potential for those interactions to develop MKT.

Research Question 2

As we outline in our Data Analysis section, to pursue our second research question about the ways that teachers' collaboration around mathematics fosters or constrains opportunities to develop MKT, we started by taking the intervals coded as "mathematics discussions" and combined them with sequential intervals to form instances. We observed seven instances of mathematics discussion in the Brantley team, although only one of those instances included multiple intervals. The Elmwood team had six instances of mathematics discussion across their four observed meetings, with two instances spanning multiple intervals. Across the two teams, the three "extended" instances of mathematics discussion all occurred during a focus on unit and lesson planning. In the sections that follow, we look more closely at two of these extended

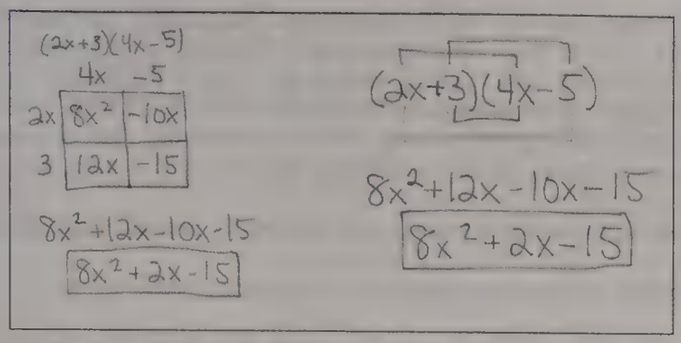

Figure 2. The "box" and "FOIL" methods for multiplying binomials.

instances—one from each group as they serve as the opportunities best suited for teachers to develop MKT due to the length and depth of the discussions. However, as we will highlight, even these opportunities were ultimately limited in their potential impact.

Brantley PLC: the multiplicative inverse and solving linear equations. In this excerpt, all five teachers of the Brantley PLC discussed a consideration brought forward by Vincent about solving linear equations, which was the focus of an upcoming unit. Prior to this excerpt, Kate had made a comment about "box" and "FOIL" processes for multiplying binomials, as are each illustrated in Figure 2. Kate's comment prompted Vincent to raise a concern about focusing on "shortcuts" versus "concepts":

This last comment by Luke was not taken up directly and was, instead, immediately followed by a discussion about the students in the teachers' classes and issues with behavior. Within ongoing discussions about practice, a teacher's distinction between a "concept" and a "shortcut" gave rise to an opportunity for the group to consider a mathematical topic and the key mathematical ideas underlying that topic. Within Vincent's comments is the implicit assertion that the "concept" when solving linear equations is that multiplying a coefficient by its multiplicative inverse will "undo" that coefficient because of the multiplicative identity, and that same multiplicative inverse must be multiplied to the expression on the other side of the equation to maintain equality. While dividing both sides of an equation by the coefficient one is attempting to deal with yields a correct answer, Vincent contends that it is merely a shortcut (and, as he raises, it is a shortcut that is useful or efficient only for certain cases).

These comments, in the context of working with students who are struggling on assessments and an upcoming unit on solving linear equations, provided the Brantley PLC teachers an opportunity to unpack aspects of these mathematical ideas in service of some of the mathematical demands of their work in the classroom. Specifically, this instance provided the Brantley teachers with an opportunity to discuss a range of ways to find a solution to a linear

Vincent:	I like to teach, you know, if you don't have a coefficient with the variable you just add the opposite of the number to each side; if you've got a variable you just multiply both sides by the reciprocal of that coefficient. In middle school they taught them, well you divide . . .
Kate:	See, I divide.
Vincent:	But that's not the concept in my opinion. That's just a shortcut.
Kate:	I teach them to undo it. So they don't recognize that they're using the inverse operation. They can tell me what the inverse operation is but they don't necessarily know that that's what it's called. Like, 'How do you undo plus two x?' . . . 'Subtract it.' 'How do you undo multiplication?' . . . 'You divide.' Because dividing and multiplying by the reciprocal are going to end up the same. It's how you choose to teach it.
Luke:	I disagree.
Vincent:	The problem is when you have like two-thirds x.
Hillary:	Plus they cannot remember how to divide the fractions. I've said it I don't know how many times in class because it comes up, like, 'When you divide, you multiply by the . . .?
Vincent:	The reciprocal.
Hillary:	[laughs] And it's crickets.
Vincent:	That's why I try to teach it that way so they've got to learn one thing: You either add the opposite or you multiply by the reciprocal. That's all you've got to know.
Kate:	I want them to get it. I don't want them to know 'multiply by the reciprocal'. I want them to solve an equation.
Samantha:	I do it the way [Kate] does it. Yesterday I really hammered home, you know, we're going to move whatever number is with x and today it gets worse because you have to pick which number you do first. If it's plus you do the opposite. So how do you get rid of a plus? You minus. How do you get rid of a minus? You plus. How do you get rid of a negative? Because that's somehow different. . .
Kate:	Especially with the number of kids who are in these reading classes, if I put the word 'reciprocal' on the board, they can't read it. They understand divide.

(Continued)

Samantha:	I've been not fighting that battle. What I've said is, 'Now I multiply by the reciprocal. Watch this.' And we've done several of them both ways. Then whatever kid I call on, that's the way we do it. We either divide or we multiply by the reciprocal because it's the same thing. So why care, as long as they get it right? But what they're not getting right is to remember to put the fraction in parentheses when you divide, because they have calculators. So as long as they can input their calculator correctly and as long as they are undoing then they are doing the correct concept. They are just not doing it in the most, what I would say, efficient way. It's much more efficient to multiply by the reciprocal.
Kate:	Another reason that I did it that way—I can't undo what all their teachers have told them in seventh and eighth grade. I have to kind of pick up where they left off.
Luke:	My problem is that, in Algebra II, you can't divide matrices. You have to multiply by the multiplicative inverse.
Samantha:	Yeah, but multiplicative inverse and reciprocal . . . like, I know it's the same but at the same time, like, this is the same thing when [Kate] says to these kids, 'Remember 'FOIL' and 'box.'' They don't remember multiplying. They remember a process, they remember a catch phrase, they remember a . . . whatever. That's why they remember 'FOIL' and 'box' because it's a catch phrase and they know the process. As long as you can jar them, they realize they're multiplying it just takes them a minute or two. . . . When they get to matrix, these kids, are you telling me that because I did divide by a fraction, they're not going to get matrix multiplicative inverse?
Luke:	No but it's the converse, which is that if they learn to multiply by the multiplicative inverse then when they get to matrices, 'Oh we just multiply by the multiplicative inverse.'

(Brantley PLC, Meeting 4, 28:41-35:49)

equation, the underlying ideas that make the strategies work, and the limitations of the strategies. Teachers also need an understanding of how concepts build throughout the progression of school mathematics, such as how work with students on solving linear equations builds on students' prior knowledge and can be constructed in ways to be built upon in the future. Luke's comment about the applicability of strategies used to solve linear equations when solving equations with matrices brings to light this aspect of the work of mathematics teaching.

However, this excerpt illustrates ways that opportunities to discuss mathematics content were pushed aside. While Vincent brought up a concern rooted in the mathematics at the focus of the discussion and Luke affirmed that concern, the discussion of the group relied more on individuals' preferences for presenting the topic—a preference determined by a teacher's perceived individualistic style and personal experience instead of the mathematics at hand or a greater sense of teaching and learning mathematics. Throughout the discussion, any potential press on a teachers' mathematical understanding was deflected to issues with students such as understanding vocabulary and in-class behavior. As a result, teachers' own understanding of the concepts and strategies discussed could have remained unchanged and, thus, not impactful on the way they know mathematics for their work as teachers. Even when mathematics was specifically discussed, once there was an implicit or explicit acknowledgment that all of members have a sense of the mathematics or an answer, the talk about mathematics became vague or moved away from the mathematics altogether.

Elmwood PLC: doing, undoing, and visualizing solving linear equations. This second excerpt also focuses on solving linear equations, this time in a discussion in the Elmwood PLC. In the excerpt, Doug demonstrated a visual model he called the "stacking boxes" method (see Figure 3). This occurred during a point early in their first meeting when teachers were sharing materials and ideas on the unit on solving linear equations. After Jackie prompted the group for any other ideas to share after initially sharing something from her own practice, Doug offered to discuss a strategy he uses with students:

Doug:	[After writing $2x + 3 = 10$ on paper at center of table] Now you start off with x because it's the only important thing on the page. I keep trying to stress it. I just don't know whether it's getting through or not, but they keep looking at the ten and the numbers and, 'What am I supposed to do with the two, the three, and the ten?' You know so, 'I'll add a ten to the three and divide by the two and that sounds good to me.' They just have no idea so, you know, what I try and do is . . . they know order of operations. Mine do.
Sabrina:	Mine do, they just can't do it right.

(Continued)

Doug: But they can tell you which one comes first.
Sabrina: Oh yeah.
Doug: So in here I've got addition and multiplication. The thing that gets done to the x first is multiplying by two [expanding on drawn image]. Then the last thing that gets done is adding by three and that equals ten. You do all of this. So it's the algebraic thinking of doing and undoing.
Pam: Take the boxes down.
Doug: Now we've got to unstack the boxes and when you unstack the boxes you take off the top first. So it's done in reverse, the order of operations, of course. So to take this box off you do 'minus three' [expanding on drawn image]. And that takes that box off and gives you seven. Then you've got to take off the multiply by two. How do you take off multiply?
Jackie: Divide!
Doug: Right.
Sabrina: Nice role playing, [Jackie]!
Doug: [Finishing drawn image] And you get that.
Sabrina: That's interesting. I've never seen anything like that before.
Jackie: He made it up!
Pam: You should get a Ph.D. . . .
Doug: [laughs] Yeah, there's an idea.
Jackie: I like visual stuff.
Doug: I try and push that now.
Sabrina: Do you do it for one-step, too? Or just two-step?
Doug: I do it with everything. As a matter of fact, you can do it, somewhat, with multiple steps. Only somewhat. If you've got on the same side . . . if the x's are still on the same side, then there's ways to . . .
Jackie: So you haven't developed anything for a variable on both sides?
Doug: There isn't . . .
Jackie: I'm guessing there is. You can do it. You need to think about that. [laughs]
Doug: Okay. Next week I'll come with something on that.
Jackie: [after a pause in discussion] Other common unit stuff?
(Elmwood PLC, Meeting 1, 5:35-9:10)

Also in the context of collectively discussing an upcoming unit, this excerpt shows another type of opportunity for teachers to meaningfully discuss mathematics in PLCs. Doug brought forward a method that he used with his students for solving particular forms of linear equations. It is important to acknowledge that Doug's method was a visual representation of a solution strategy and, as a result, was not intuitive. The representation corresponds to the steps one uses when solving a linear equation through symbolic manipulation. The discussion around Doug's strategy provided an opportunity for teachers to unpack the concepts that underlie procedures used to solve linear equations and, thus, potentially develop MKT.

In presenting his idea, Doug modeled the strategy as a "teacher" with the others observing and interacting as "students," brought to the forefront with Jackie's response ("Divide!") to Doug's leading question ("How do you take off multiply?") and Sabrina's acknowledgment of Jackie's "role playing." Doug created a written representation of the work involved with the method on the particular problem ($2x + 3 = 10$), which provided a concrete record for teachers to discuss. The conversation at the end of the Elmwood vignette is noteworthy as Doug was pressed to consider the limitations of the method. While this press was responded to with uncertainty from Doug and a claim that lacked any backing from Jackie ("I'm guessing there is"), overall the discussion took a different form than that of the Brantley teachers. Instead of evaluating an idea from the standpoint of how that idea aligned with one's personal

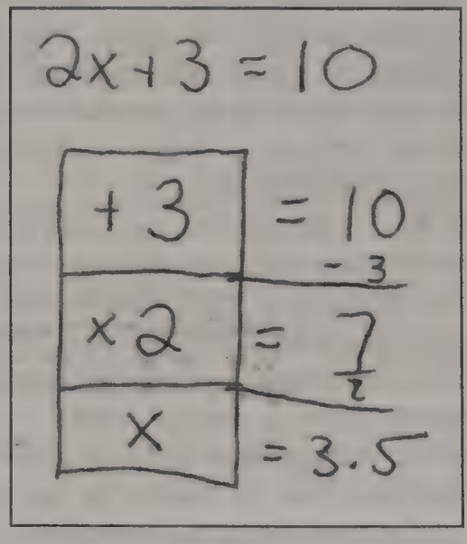

Figure 3. Doug's "stacking boxes" method of solving linear equations.

style, the Elmwood PLC talked about Doug's method in a way that at least opened up the opportunity for them to think more about the method and the underlying mathematics (although many comments and mathematical ideas remained unchecked).

Developing MKT in PLCs: Discussion and Implications

Our analyses provided insight into the interactions of two teams of mathematics teachers—each operating under the premise of being a PLC—and the way in which their collaborative interactions provided space for teachers to develop MKT. Both groups had positive collaborative norms, with each group having some general foci (such as looking at assessment data or engaging in common planning) and engaging in what might be characterized as dynamic discussion (involving all teachers, turn-taking, sharing of tentative ideas). Yet, core to our study, discussions specifically focused on mathematics in these groups were rare. Additionally, even in those few opportunities, there were many factors at play that hindered the potential development of MKT. In this section, we highlight two considerations that arise from these findings related to considering the role PLCs, in general, can play in teachers' mathematical development.

Multiple Goals of PLC Interactions and the Role of Teachers' Mathematical Development

In addressing our first research question regarding the extent to which these teachers' discussions focused on mathematics content in their PLCs, we found that teachers' discussions seldom included reference to (and far less a focus on) specific mathematics content. However, our findings also highlight multiple goals that can be driving the substance and form of teachers' interactions in PLCs. These goals may be prescribed by a district or school or may originate from teachers' own needs. Even in a group comprised entirely of mathematics teachers, those goals might not always be taken up in ways that are specifically mathematical and, furthermore, might not involve teachers' own mathematical development.

This raises the question of why we would expect to see more in terms of mathematics discussions and opportunities for teachers' development of MKT if that was not a purpose of these teachers' interactions. With this work, we address an assumption that mathematics teacher collaboration around their mathematics teaching practice would be inherently mathematical. Our findings show that is not reliably the case. A similar question to ask is whether or not the lack of mathematics discussions among these teachers was a sign of them being unproductive, even if they were attending to other stated goals. We do not see this work as a claim that evaluating the whole of these teachers' interactions should be based only on their mathematical focus, as other investigations could focus on teachers' use of assessment data, student work, or common planning. However, our findings suggest that the way PLCs have been broadly characterized—as a panacea for all things related to student, teacher, and school improvement, including teachers' content knowledge—is an overstatement. This is not a wholesale critique of PLCs, although it is an assertion that expectations for PLCs involving teacher development, specifically around content knowledge, will need to be supported in specialized ways, such as the case with work described by Borko and her colleagues (2015) and others. Our findings raise doubts about the ways that a general notion of teacher collaboration, even among mathematics teachers exclusively, will necessarily support teachers' mathematical development.

The Specialized Nature of Doing and Discussing Mathematics as Teachers

From our work toward our second research question, we also highlight how the lack of opportunity for teachers to develop MKT in PLCs is not just a matter of time being spent on other things. Even if teachers were to spend more time discussing specific mathematics content, the vignettes we shared demonstrate some of the ways in which those conversations would continue to be limited in terms of their mathematical focus. Based on our findings and on previous research on teacher PD, we highlight two additional factors that play a role in the nature of teachers' collaborative mathematics discussions.

First is the way in which teachers' conversations about mathematics need to be different that mathematical discussion with students because of differences in the purposes of such discussions (Elliott et al., 2009). In our data we saw two ways in which mathematics discussions played out—both with shortcomings when it comes to the potential for teacher development. The example from the team at Elmwood showed teachers engaging with a procedure brought forth by Doug in a way that was reflective of how students might engage with the teacher and the content. While teachers learned about Doug's idea, that alone did not engage teachers with the mathematics underlying that idea. This form of "modeling" of instruction is not sufficient for engaging teachers in mathematics.

With the Brantley team, we saw mathematical conversation that did not look like what you might expect to see in a school classroom, although the discussion was also not rich in terms of the opportunities for teachers to develop MKT. In the case of the Brantley team, there was

most often a distance from the mathematics, even when mathematics was being referenced or discussed. The teachers only interacted verbally, with no ideas being recorded or built upon. The discussion also repeatedly moved to non-mathematical topics, such as student behavior or school issues. The segments of conversation that were focused on mathematics were comprised mostly of broad statements about mathematics and statements of teachers' personal preferences, as opposed to about the substance of the mathematics at hand. We found it interesting that a group of mathematics teachers collaborating around their mathematics teaching practice would not be sufficient for creating discussions that were mathematical in nature. However, these practices are reflective of issues reported by others, such as Elliott and her colleagues (2009), regarding teachers' reluctance to dig into mathematics with peers in PD settings because of status issues or assumptions that are made.

One way to support teachers' discussions of mathematics would be the role of a skilled facilitator (Borko et al., 2015; Elliott et al., 2009; Fulton et al., 2010; Lesseig et al., 2016). In our data, such a skilled facilitator was not present. Teachers from within the group took on leadership roles—sometimes with multiple people taking on different aspects of leadership needs. Those needs included maintaining an agenda for group meetings and attending district-wide meetings. Other leadership roles, such as department chair, could have also had an influence on the work of the group. However, none of the teachers on either team were tasked with or prepared for facilitating teachers' engagement with mathematics. With the presence of such a skilled facilitator and an explicit focus on developing MKT, examples such as those put forward by Borko and her colleagues (2015) and Brodie (2014) show that teachers can work meaningfully on mathematics in the context of their collaborations. However, our data show that without such support, the likelihood of teachers developing these mathematical resources through their practice-focused conversations is greatly diminished.

Conclusion

In this article, we examined the extent to which mathematics teachers collaborating as a PLC focused on mathematics content as part of their discussions and how their discussions about mathematics might have provided opportunities for teachers to develop MKT. By focusing on MKT, we echo the recent work of many who are specifying the nature of teachers' mathematical knowledge and the ways in which such knowledge is developed (Ball et al., 2008; Borko et al., 2015; Elliott et al., 2009). We found that even with groups of mathematics teachers talking within the context of their mathematics teaching, mention or discussion of specific mathematics content was rare. In the event of conversation that did focus on specific mathematics, the prevailing ways of working in the group hindered the potential of those discussions as opportunities for teachers to develop MKT. We see these findings contributing to a needed discussion around whether PLCs, especially those not formed as part of a more specified PD effort or provided other specialized supports, can reliably and consistently serve as a site for teachers' mathematical development. These findings do not cast doubt on the potential of benefits of PLCs in general, nor do they negate the impact of the small set of examples in the literature of successful PLCs focused specifically on teachers' mathematical development. Given the way research and anecdotes on school improvement are taken up at school, district, and state levels, these findings present the need for future work on PLCs (and PD in general) to take more care in reporting on the way a design is intended to support teachers and its ultimate impact.

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The Influence of an Internet-Based Formative Assessment Tool on Primary Grades Students' Number Sense Achievement

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This study examined primary grades students' achievement on number sense tasks administered through an Internet-based formative assessment tool, Assessing Math Concepts Anywhere. Data were analyzed from 2,357 students in teachers' classrooms who had participated in a year-long professional development program on mathematics formative assessment, 1,427 students from teachers who had participated in the program in the year prior, and 9,783 students whose teachers had not participated at all. Analyses indicated that all students in the treatment group demonstrated growth, and that student achievement was influenced by the number of times the assessment was used to collect data and make instructional decisions. Further, there was a relationship between districts' socioeconomic status and growth, meaning students from impoverished backgrounds grew more than their peers.

Overview

The Need to Improve Students' Mathematics Achievement

In the current era of educational accountability, educational leaders and researchers are constantly seeking ways to increase students' achievement and learning. While a teachers' effectiveness continues to be identified as the most influential variable on students' learning, there is a need to more explicitly identify the teacher practices and characteristics that have the greatest benefit to students (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Hattie, 2009; Nye, Konstantopoulos, & Hedges, 2004).

Research studies have cited efforts to positively impact student achievement specifically chronically low-performing students, especially those from impoverished backgrounds (National Center for Educational Statistics [NCES], 2013; Organisation for Economic Co-operation and Development, 2012). Analyses of data collected from the Programme for International Student Assessment indicate vast differences across the world about how mathematics is taught as well as varied levels of performance on the assessment. These differences, while somewhat associated to levels of poverty, are largely caused by differences in teacher quality and the types of pedagogies used during mathematics instruction (Hattie, 2011; Nye et al., 2004).

Targeted Teaching and Formative Assessment

Benefits of formative assessment. Worldwide, the idea of using data to inform teachers' instruction has been advanced (Goss, Hunter, Romanes, & Parsonage, 2015; Means, Padilla, DeBarger, & Bakia, 2009). Goss et al. (2015) cited the positive impact of targeted teaching, in which teachers design instruction that is differentiated and designed to target students' individual needs. More than ever, classrooms have a wide variety of ability levels in a classroom (Santiago, Donaldson, Herman, & Shewbridge, 2011), and studies indicate that streaming curriculum by teaching without differentiation or targeted instruction has a negative impact on student achievement (Education Endowment Foundation, 2015). Black and Wiliam (1998) also found that using data to make instructional decisions led to significant gains in student achievement in mathematics.

In a meta-analysis of over 800 studies Hattie (2009, 2011) identified specific educational factors that are significantly associated to positive student achievement. One of the most impactful factors is teachers' use of formative assessment strategies. Multiple meta-analyses of research studies have found that, when implemented well, formative assessment practices can effectively double the speed of student learning (Wiliam, 2007/2008).

Formative assessment practices involve the process of collecting student data, analyzing it, and using it to plan, modify, and implement instruction that addresses students' specific needs. In this article, we refer to formative assessment to the entire process of all of these activities. Empirical studies show the benefit of formative assessment practices on student achievement in literacy

(Fuchs & Fuchs, 1986) as well as mathematics (Wiliam, 2007, 2010). Formative assessment refers to the evaluation of student learning during the learning process with student learning as its main priority. The literature suggests several components of effective formative assessments: (a) opportunities for teachers and students to express learning goals; (b) use feedback to move forward; (c) engage in peer assessment; (d) uncover student reasoning; and (e) create follow-up instruction that extends thinking (Baroudi, 2007; Heritage, 2007; Hodgen, 2007; Huinker & Freckmann, 2009). Empirical studies indicate that student achievement significantly increases when teachers use formative assessments appropriately (Black & Wiliam, 1998; Wiliam, 2007). Teachers who use formative assessment are able to better understand the learner and use the data for the development of individualized instruction for each specific learner.

A meta-analysis was employed to examine the effects of systematic formative evaluation and noted that the effect sizes were significant for students whose learning processes were monitored systematically (Fuchs & Fuchs, 1986). Moreover, effect sizes were even higher when teachers used data-utilization rules. Fuchs and Fuchs (1986) work also found that for struggling learners who are sometimes referred to as *at-risk*, formative assessment practices started to close the achievement gap in literacy. Related studies are needed in the field of mathematics.

Internet-based tools for formative assessment. In the 21st century, there have been many formative assessment tools or programs developed and used in order to support teachers' planning and implementation of differentiated instruction. Some of these are used exclusively for the collection and analysis of student performance only, requiring teachers to analyze data and plan further instruction. Others are generative or adaptive learning programs that include opportunities for teachers to formatively assess their students as well as instructional activities that are completed on an Internet-connected device such as a computer or iPad.

The commercial companies that produce the generative and adaptive programs have data that shows that the use of their program leads to gains in student learning on either their assessment items or in some cases state-wide assessments (Center for Educational Policy Research, 2016; Curriculum Associates, 2016; Educational Research Institute of America, 2015). However, these evaluation studies indicate that not every student benefits from the use of these tools, control groups are not used to compare students who use these programs with those who do not, and there are other confounding variables not controlled for such as other mathematics resources and the quality of mathematics instruction or teacher characteristics. Still, these evaluation reports indicate a need to further investigate how these programs are used and how they influence student learning.

The other programs, such as the one examined in this study, provide teachers with formative assessment data on their students' performance that teachers can then use to plan subsequent instruction to meet their students' learning needs. In a recent study, Herndon (2015) found that teachers were using MClass, an Internet-based formative assessment tool for reading, but struggled to use the data to plan instruction that specifically aligned to their students' reading levels.

In mathematics, the only research published on teachers' use of formative assessment data collected through an Internet-based tool has been done by the authors of this current study. Past studies echo the findings of the Herndon (2015) study in that teachers assessed their students using AMC Anywhere, but reported difficulty finding the time and knowing exactly how to reconcile their assessment data, their mathematics resources, and the state mathematics standards (Martin, Polly, Wang, Lambert, & Pugalee, 2016). Still, some studies from AMC Anywhere document evidence that despite reporting struggles that teachers successfully analyzed data, designed and implemented instructional activities that aligned to their students' mathematics performance (Polly, Martin, Wang, Lambert, & Pugalee, 2016).

Formative Assessment in Mathematics

In mathematics education, formative assessment has long been identified as a high-leverage and impactful instructional practice (NCTM, 2000, 2015; Wiliam, 2007; Wiliam & Thompson, 2007). Formative assessment research cites that the practice is most valuable to the teaching and learning when teachers use data to modify instructional goals, instructional activities, and instructional pedagogies (Heritage, 2007).

The research base has documented teachers' difficulties carrying out the various aspects of formative assessment practices (Pfannkuch, 2001; Polly et al., 2014; Wiliam & Thompson, 2007). Abrams (2007) noted that teachers opted to not collect data frequently due to the time demands associated with planning and teaching their standards. In essence, teachers did not feel that they had the time to implement formative assessment. In New Zealand, Pfannkuch (2001) conducted a 10-year longitudinal study and found that while primary-grade teachers used a variety of assessment practices, they were focused on mastery learning and did not include a lot of formative or informal

assessments of students' mathematics learning. She found an abundant number of assessments meant to assess mastery at the end of teaching rather than formative assessment practices during instruction.

Higgins and Parsons (2009) researched the nationwide professional development project in New Zealand and found that teachers were able to effectively support their students' development of number sense through an integrated professional development model that included a research-based framework about number sense, the use of diagnostic interviews with students, and a strategy-specific teaching model. Through classroom observations and teacher interviews, New Zealand teachers shared about their increased use of diagnostic interviews and formative assessment practices as well as the gains in their students' understanding of number sense (Higgins & Parsons, 2009).

Formative Assessment on Children's Number Sense

Research studies from the same project as this present study indicate that professional development focused on diagnostic interviews and the process of making instructional decisions based on the data was associated with students' achievement in number sense (Martin et al., 2016; Polly, Martin, Wang, Lambert, Pugalee, & Middleton, 2016). In terms of number sense, we refer to what Gersten and Chard (1999, p. 18) referred to as "a child's fluidity and flexibility with numbers, the sense of what numbers mean and an ability to perform mental mathematics and to look at the world and make comparisons."

Within the five aspects of mathematical proficiency described by National Research Council (2001), this study focused on students' conceptual understanding and procedural fluency as it relates to students' number sense skills. Conceptual understanding is defined as the comprehension of mathematical concepts, operations, and relations and whether or not students are able to demonstrate their knowledge through the creation and manipulation of mathematical representations. Meanwhile, procedural fluency refers to skills in carrying out procedures flexibly, accurately, efficiently, and appropriately, such as the mathematical operations. In primary grades mathematics, the foundational number sense skills focus on counting, addition and subtraction fluency, and building an understanding of ten and place value (Richardson, 2012).

Clearly, formative assessment practices and teaching that is driven by data and targeted to meet students' needs has potential to increase students' achievement in mathematics. However, there is a need to examine how to best support teachers' use of formative assessment practices as well as a need for more research about the influence of formative assessment on students' achievement in mathematics. This study focuses on teachers' use of formative assessment with primary-grade students about their understanding of number sense.

Purpose and Research Question

This study focuses on the research question: Is there a significant relationship between teachers' use of the Internet-based formative assessment tool AMC Anywhere and student growth in mathematical skills? Specifically, variables such as poverty, school size, and the frequency of the use of formative assessment practices were examined as possible influences on the variance of students' achievement.

Methods

Context of the Study

The data analyzed in this study came from teacher-participants in a year-long professional development project funded by the Mathematics Science Partnership grant program in the United States. Teachers participated for one year in 80 hours of learning about formative assessment, how children develop number sense, and the use of an Internet-based formative assessment tool, *Assessing Math Concepts* (AMC Anywhere, Richardson, 2012). Teachers also learned about using the data from the tool to select and modify instructional activities from the *Developing Number Concepts* (DNC) curricular resources (Richardson, 1998). DNC resources were only available to those in the professional development and participants from the previous year. All participating teachers, including comparison group teachers, were also using the reform-based mathematics curricular resources, *Investigations in Number, Data, and Space* (TERC, 2007). Therefore, the project also included support aligning the concepts in the assessment to curricular resources and the state mathematics standards, which were the Common Core State Standards for Mathematics (CCSSI, 2011).

AMC Anywhere is an Internet-based tool that supports the process of conducting diagnostic interviews on students' mathematics understanding. Teachers use AMC Anywhere in a one-on-one setting, in which students solve tasks either with manipulatives, such as counters, 10 frame mats, or snap cubes, or using mental mathematical reasoning. Teachers pose tasks to students, who complete the tasks, and then the teacher records students' responses and strategies in the tool. The tool includes a built-in rubric, which then provides teachers with a rating on the assessment, which aligns to the instructional materials from the DNC resources. The expectation in this project is that teachers used the assessment with every student in their class and then used the data to plan and implement differentiated, targeted instruction.

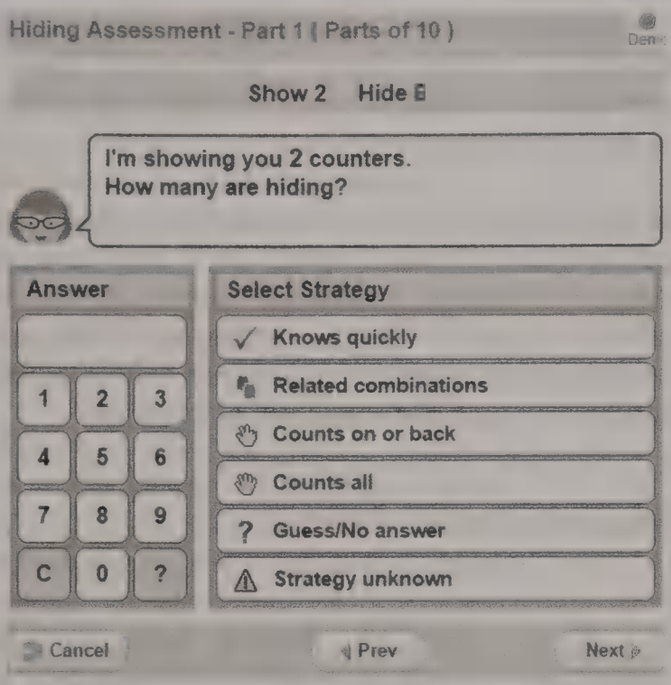

Figure 1. Screenshot of Hiding Objects Recording Screen. [Color figure can be viewed at wileyonlinelibrary.com]

While AMC Anywhere includes nine different assessments, this study examined only student learning data from the Hiding Assessment. The concepts in that assessment align to decomposing a number into two smaller numbers in kindergarten, missing addend and decomposing a number in Grade 1, and addition and subtraction fluency in Grade 2.

The Hiding Assessment includes two separate parts with distinct tasks. Part One requires students to find the missing addend of numbers using counters to assist students. For example, in Figure 1 students count out 10 counters and the teacher then removes 8 counters when the students are not looking. The student looks at the pile, sees two counters, and has to then determine how many counters the teacher took away or is hiding. Part Two consists of the same tasks, but without counters and only mental reasoning. Both parts assess students' ability to differentiate ways to solve tasks involving the numbers 3 through 10.

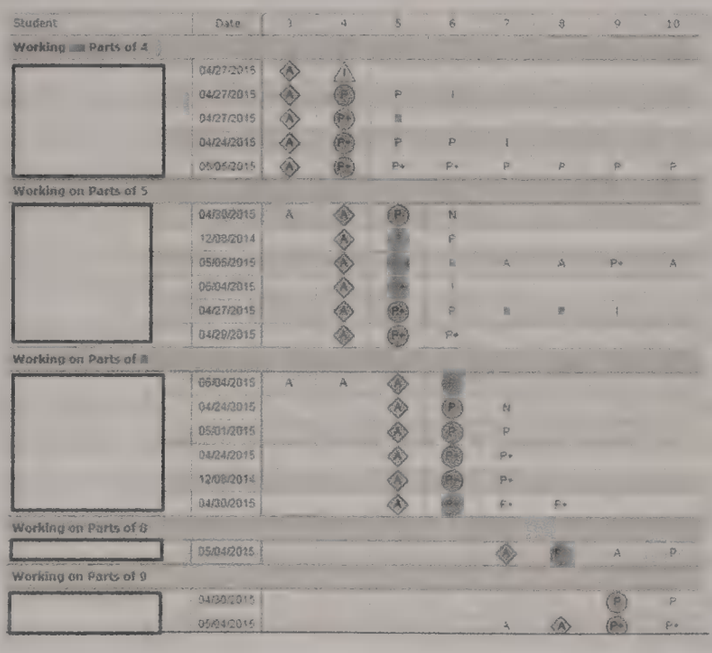

Figure 2. Screenshot of Classroom Instruction Report for Hiding Assessment. [Color figure can be viewed at wileyonlinelibrary.com]

As an Internet-based tool, AMC Anywhere allows teachers to collect, store, and analyze data from the diagnostic interviews throughout the school year as well as across school years for students. Further, its reporting features provide teachers with information about students' instructional needs as well as links to the accompanying curricular resources, DNC (Richardson, 1998), which provide activities for students to explore related to the skills in the assessments. The DNC activities can be differentiated easily to meet students' mathematics needs. Figure 2 shows a screenshot of the classroom report from AMC Anywhere, while Table 1 provides an example about how the assessments link to instructional activities. The goal of AMC Anywhere and DNC is that teachers would use formative assessments as an integral part of the process of analyzing students' mathematical understanding.

Participants

Participants in this study include 906 teachers and their 13,567 students in Grades K–2 in elementary schools in North Carolina. Of these 13,567 students, 763 (6%) were in kindergarten, 5,815 (43%) were in the first grade, and 6,989 (51%) were in the second grade. These students were put into three groups: treatment group ($n = 2357$, 17%), prior-year group ($n = 1427$, 11%), and comparison group ($n = 9783$, 72%), Treatment group students are from the 127 (14%) teachers who participated in the 80-hour professional development who were asked to use AMC Anywhere at least three times as part of the project. Prior-year group students are from the 81 (9%) teachers who participated in the professional development program last year who still had access to AMC Anywhere and were encouraged by their school district to still use the assessment. The rest of the teachers ($n = 698$, 77%) and their students served as the comparison group. The teachers in the comparison group used AMC Anywhere, but never participated in any professional development about using the data as part of the formative assessment process. The data from all the students were available to the researchers through the AMC Anywhere website. These data are anonymous, and we have obtained the waiver of consent forms from these participants with the approval of the

Table 1
Chart Aligning the Hiding Assessment to Instructional Activities (Used with permission from Richardson, 2012)

Independent Activities for Needs Instruction (I)		To 6	To 10
2:2-14	Number Arrangements: Using Cubes	X	X
2:2-15	Number Arrangements: Using Color Tiles	X	X
2:2-16	Number Arrangements: Using Toothpicks	X	X
2:2-17	Number Arrangements: Using Collections	X	X
2:2-18	Counting Boards: Making Up Number-Combinations Stories	X	X
2:2-20	Number Shapes: Using Number Cubes	X	X
2:2-21	Number Shapes: Using Spinners	X	X

Institutional Review Board at our university. Since this is not an experimental design, we are aware of the potential differences in teacher and student characteristics of the three groups of teachers with their students. These differences make simple mean comparisons across the groups meaningless. Therefore, we adopted a linear growth model that estimates the initial status of the student's mathematics achievement at the beginning of the treatment and the monthly growth rate for all students. Linear growth models accommodate various initial status as well as nonsimultaneous data collection at the same time (Raudenbush & Bryk, 2002).

All teacher-participants hold a state license in elementary education which spans from kindergarten through Grade 6 (ages 5 through 11). Additionally, all teachers in the study use an Internet-based formative assessment tool, MClass (Amplify, 2015), which the state mandated to assess students' literacy development. The state has not mandated the use of a formative assessment tool for mathematics.

Data Analytical Procedure

The researchers used Item Response Theory to transform the teachers' assessment of student mathematical skills from the original letter grade scaling into interval-level scale scores using the Rasch model (Andrich, 1978; Martin, Lambert, Wang, & Polly, 2017) with Winsteps software (Linacre, 2012). The standardized scaled scores have a mean of 500 and a standard deviation of 100. Since students were assessed multiple times during the academic year, month was used as the unit of analysis in time so that each assessment is associated with the number of months elapsed from the start of the academic school year (August 15). Due to the nature of nested data in our project (student data are nested within classrooms and classroom data are nested within schools), a multilevel data analytic procedure (i.e., hierarchical linear models) was adopted to account for the variances between classrooms as well as between schools (Raudenbush & Bryk, 2002). A four-level hierarchical linear model (HLM4) was employed to predict the student initial status of mathematical skills as well as the monthly growth rate for the students during the academic year at Level One. Level One is simply a linear growth model where the dependent variable is the student performance on the mathematics achievement measure (i.e., hiding task) and the independent variable is time (coded as 0 if the measurement took place in August, 1 in September, 2 in October, etc. so that the slope of the regression represents monthly increase). The number of assessments each student received (Assessment) was used as a predictor (group-mean centered) at Level Two (Student Level). At Level Three, the average number of assessments in each classroom (Mean_Assess) and the group status (treatment group versus comparison group) were entered as predictors [group-mean centered, Classroom Level]). Finally, the school size (size) and the percentage of free/reduced price lunch children (poverty) were used as predictors (grand-mean centered) at Level Four (School Level).

Table 2
Descriptive Statistics for Student Performance on Hiding Assessment

	Part One (Initial)	Part One (Final)	Part Two (Initial)	Part Two (Final)
Prior-Year	447.55 (66.96)	587.81 (76.17)	458.32 (65.72)	586.63 (70.58)
Treatment	439.59 (60.07)	570.88 (65.52)	450.68 (61.25)	571.49 (67.35)
Comparison	441.16 (70.26)	560.61 (71.87)	453.51 (68.23)	559.74 (72.61)

Note. Numbers in parentheses are standard deviations.

Table 3
Estimation of Fixed Effects for HLM4 of Hiding Assessment

			Part One			Part Two		
		Level	Estimate	*SE*	*df*	Estimate	*SE*	*df*
Intercept		1	411.62	13.00***	135	453.87	13.18***	150
	Assessment	2	−10.03	2.71***	2557	−9.64	3.34**	2340
	Mean_Assess	3	4.36	4.66	34	0.87	6.77	37
	Group	3	−32.07	10.23**	34	−34.03	11.16**	37
	Size	4	−.01	.02	135	−.05	.02**	150
	Poverty	4	−1.94	.31***	135	−1.42	0.33***	150
Slope		1	11.58	1.27***	2912	7.30	1.46***	1664
	Assessment	2	.45	.32	2912	.97	.42*	1664
	Mean_Assess	3	.78	.30**	2912	.62	.47	1664
	Group	3	.90	.62	2912	.21	.72	1664
	Size	4	.001	.002	2912	.008	.002***	1664
	Poverty	4	.05	.02**	2912	.01	.02	1664

Note. $^{**}p < .01$; $^{***}p < .001$.

Results

Group Mean Differences

Descriptive statistics of student performance on the Hiding assessment are reported in Table 2. Only the initial status and the final score of the students in each of the three groups were included because each student was measured multiple times (ranged from 1 to 13). The assessment that was administered at the beginning of the school year (i.e., August or September) was treated as the initial status, whereas the assessment that was administered at the end of the school year (i.e., April or May) was treated as the final score of the student performance on the Hiding assessment.

Estimates of the Initial Status and Monthly Growth Rate (Part One)

The parameter estimates of the fixed effects for HLM4 are presented in Table 3. In Part One of the Hiding Assessment, a comparison group student's performance in an average classroom and at a school of average level of poverty is estimated to be 411.62 at the beginning of the academic year (August 15), and the monthly growth rate of the student is estimated to be 11.58, which means that a student's performance on this assessment is expected to increase by 11.58 every month. Students from poverty schools were at significantly lower levels at the beginning of the academic year, $t\ (135) = -6.24$, $p < .001$. This negative relationship between poverty level and student achievement is manifested as: With an increase of one percent of students who are qualified for free/reduced price lunch program in the school, students' achievement in this assessment is estimated to be 1.94 lower.

Across all the students, treatment group students' initial performance on the assessment was significantly lower than that of the comparison group students, $t\ (34) = -3.13$, $p = .004$. Students in the treatment group were expected to be 32.07 less than that in the comparison group at the beginning of the academic year. This means that the teachers who volunteered to be in the comparison group are from classrooms whose students are above the average level of performance, assuming that all the treatment group students are from average classrooms. Moreover, the number of assessments that each student received is negatively related to the estimated initial status of the assessment, $t\ (2557) = -3.71$, $p < .001$. With each additional assessment, a student's initial status is expected to be 10.03 less, which suggests that the teachers used AMC Anywhere more with the students who had more difficulty in learning mathematics. The other two predictors of the intercept (classroom mean number of assessments and school size) did not have any statistically significant impact on the estimation of the initial status of the assessment.

As for the predictors of the slope, classroom mean number of assessments had a statistically and significantly positive impact on the monthly growth rate, $t\ (2912) = 2.62$, $p = .009$. For each additional assessment in the classroom level, students' monthly growth rate is expected to increase by .78, i.e., from 11.58 to 12.36. Similarly, the school average poverty level also had a significantly positive impact on the monthly growth rate, $t\ (2912) = 2.88$, $p = .004$. With an increase of one percent of students eligible for the free/reduced price lunch program, the students' monthly growth rate is expected to increase by .05, i.e., from 11.58 to 11.63. The other predictors in the model (school size, classroom mean number of

assessments, and the number of assessments for each student) did not have any statistically significant impacts on the monthly growth rate.

Estimates of the Initial Status and Monthly Growth Rate (Part Two)

For Part Two of the Hiding assessment, a comparison group student's performance in an average classroom and at a school of average level of poverty is estimated to be 453.87 at the beginning of the academic year (August 15), and the monthly growth rate of the student is estimated to be 7.30, which means that a student's performance on this assessment is expected to increase by 7.30 every month. This monthly growth rate (slope) is statistically significantly different from zero, $t\,(1664) = 5.01, p < .001$. Students from large schools (more than a thousand students) were at significantly lower levels at the beginning of the academic year in comparison to small schools (less than 500 students), $t\,(150) = -2.98, p = .003$. Students from poverty schools were also at significantly lower levels at the beginning of the academic year, $t\,(150) = -4.29, p < .001$. With an increase of one percent of students who are qualified for free/reduced price lunch program in the school, students' achievement in this assessment is estimated to be 1.42 lower. Treatment group students' initial status of the assessment was significantly lower than that of the comparison group students, $t\,(37) = -3.05, p = .004$. Students in the treatment group were expected to be 34.03 less than that in the comparison group at the beginning of the academic year. Moreover, the number of assessments that each student received is negatively related to the estimated initial status of the assessment, $t\,(2340) = -2.89, p = .004$. For each additional assessment, a student's initial status is expected to be 9.64 less, which suggests that the teachers targeted at the students who had more difficulty in learning mathematics and gave these students more assessments during the academic year. The other predictor of the intercept (classroom mean number of assessments) did not have any statistically significant impact on the estimation of the initial status of the assessment.

As for the predictors of the slope, school size had a positive impact on the monthly growth rate, $t\,(1664) = 3.54, p < .001$. With an increase of 100 students in the school population, students' monthly growth rate is expected to increase by .20, i.e., from 7.30 to 7.50. Similarly, the number of assessments each student received also had a significantly positive impact on the monthly growth rate, $t\,(1664) = 2.88, p = .004$. For each additional assessment, the student's monthly growth rate is expected to increase by .42, i.e., from 7.30 to 7.72. The other predictors in the model (school poverty level, classroom mean number of assessments, and the treatment or comparison group status) did not have any statistically significant impacts on the monthly growth rate.

Discussion

The findings from this study related to the significant relationships between school-level poverty, school size, and the number of assessments on the monthly growth rate of student achievement warrant further discussion. Additionally, there are implications for future research and practice based on this study.

Relationship Between Poverty Level and Student Achievement

In Part One of the assessment where students found missing parts of numbers using counters, the school-level poverty had a positive impact on the growth rate, and students from schools with lower socioeconomic status showed statistically significant growth compared to others. These findings must be taken with caution due to the difference in achievement at the beginning of the study. Students in poverty and large schools were found to be significantly lower-achieving in mathematics at the beginning of the school year, which is a possible explanation why these students are relatively making a faster growth. This finding suggests that the use of the AMC Anywhere formative assessment tool led to growth in this disadvantaged group of students, and helped to decrease the achievement gap between impoverished settings and other students.

The differences in student achievement between students from higher and lower socioeconomic settings have been noted in large-scale studies (NCES, 2013, 2015). While prior studies have identified positive relationships between formative assessment and student achievement (Hattie, 2011; Polly et al., 2014; Wiliam & Thompson, 2007), this study found statistically significantly greater gains for impoverished students as a result of formative assessment in mathematics. This extends earlier work done in literacy (Fuchs & Fuchs, 1986), only this study focuses specifically on number sense with primary grades' students. Future studies should explicate and further detail the processes of teachers enacting formative assessment practices for all students within classrooms to see if their decisions and actions differ depending on their students' abilities.

School Size and Student Achievement

In Part Two of the assessment, school size had a positive impact on the growth rate. Larger schools were associated with higher growth rates. This finding, however, does not mean that students in larger schools have better performance on the assessment because students in larger schools were

found to have lower initial status at the beginning of the academic year. The higher monthly growth rate can be explained by the well-known effect that disadvantaged schools show more growth. One possible explanation for this higher growth rate in large schools could be the amount of support and collaboration at larger schools, which led to a higher fidelity of implementation of AMC Anywhere and formative assessment processes. In prior work, researchers found that teacher collaborative structures, sometimes termed professional learning communities, led to greater implementation of reform-based practices (Dufour, Dufour, & Eaker, 2008; Martin & Polly, 2015).

In the school districts that participated in the project, larger schools often had mathematics-specific support, such as a mathematics facilitator or coach. These personnel typically assist in instructional planning, and preparation for the enactment of specific practices, including formative assessment (Martin & Polly, 2015). Future work should see what specific aspects these larger schools have that may lead to these statistically significant differences.

Number of Assessments and Student Achievement

Another noteworthy finding was the positive relationship between the number of assessments for students and the monthly growth rate of student achievement. The implication of these findings suggests that teachers should be encouraged to use assessments more frequently in classroom instruction not only to better understand the student's status of learning but also to make the students aware of their own progress. This interpretation is really important, because a close examination of the frequency distribution table suggests that most of the students (99%) were assessed less than eight times. Students who were assessed between 8 and 13 times only consisted of 1% of the sample. We understand that it is not only the dosage effect but the use of formative assessment that provides feedback to the teacher that helps the students improve their number sense. The information that the teacher gained from analysis of these formative assessments guided their instruction and made differentiated instruction possible. A close look at the scatter plot (Figure 3) between the number of assessment and the student performance in the end of the academic year suggests that students who were assessed more than three times (which is required for all teachers who participated in the professional development program) were all above the average. While this work is similar to prior findings (Polly et al., 2014; Wiliam & Thompson, 2007), the significant relationship between the number of assessments, poverty level, school size, and student achievement is novel and contributes to the knowledge base.

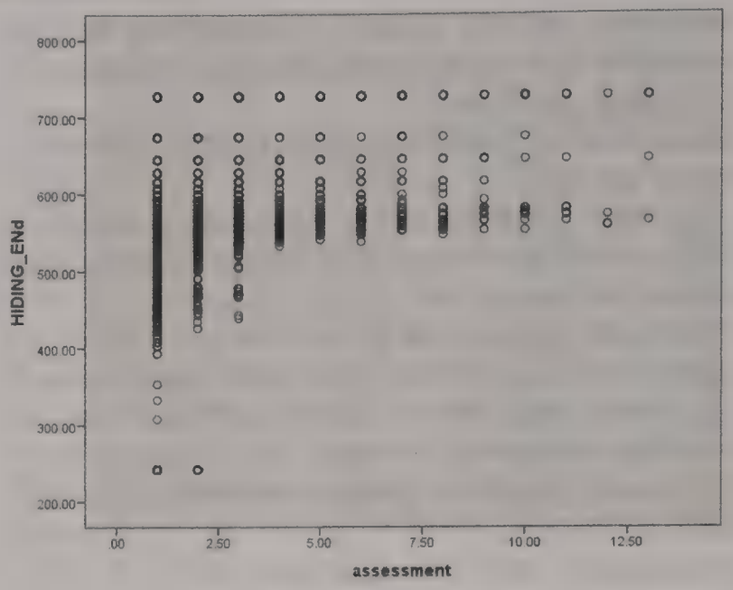

Figure 3. Scatter plot of the relationship between the number of assessments and student performance in the end of the academic year.

Further, the findings indicate that teachers used the AMC Anywhere formative assessment tool more frequently for lower-performing struggling learners. Based on this finding and data from prior work (Martin et al., 2016), we interpreted this finding to mean that teachers gave struggling students more frequent assessments to determine if they still need more assistance. However, in prior work (Polly et al., 2014), there were no statistically significant differences between poverty level and achievement.

Implications

Internet-based technologies continue to be purchased by state departments of education, school districts, and schools in order to support teachers' formative assessment practices. In this present study, there were statistically significant relationships between the use of formative assessment practices and primary-grade students' achievement on number sense tasks using the Internet-based tool AMC Anywhere. Further, students from impoverished settings, larger schools, and students who were assessed more frequently were associated with greater growth than their peers.

While the findings are promising, there is a need for further studies. Future research is needed to further detail teachers' specific assessment practices, the frequencies they are collecting formative data, and how those data are used to plan differentiated instruction in mathematics. Statewide, each participating teacher was using standards-based mathematics curriculum, as well as DNC resources to teach the Common Core State Standards in Mathematics. Subsequent studies should examine how the combination of specific curricular resources and formative assessment

practices influence student achievement on multiple learning outcomes such as AMC Anywhere and other mathematical tasks. Further, little is known about teachers' day-to-day process of analyzing data and making instructional decisions. While AMC Anywhere was used a few times a year, more research is needed to examine teachers' daily use of more informal formative assessment practices related to number sense as well as other mathematics concepts.

One limitation that we acknowledge is the repetitive use of the same assessment. However, we think that growth from simply completing the assessment multiple times is unlikely. First, the questions in the AMC Anywhere system are generated by the tool and are never in the exact same order. Second, students were solving questions in a one-on-one setting with their teacher, where both the answer and the strategy used to find the answer was found. These strategies focus on developing fluency and efficiently finding the missing part when a number is decomposed. Based on this, we are convinced that growth on the assessment includes a deeper understanding of decomposing numbers.

Last, our body of research studies have identified that despite professional development and access to AMC Anywhere, some teachers do not use the tool much to assess their students or they inconsistently enact formative assessment practices (Martin & Polly, 2015; Polly et al., 2014). As a result, there is a need to examine ways to best support teachers' adoption of formative assessment practices. For some teachers, the use of an Internet-based tool such as AMC Anywhere may be ambitious, and more informal, paper-based assessments may be more feasible as a starting point for supporting teachers' use of formative assessment processes. There is a need to support and research teachers' adoption of formative assessment practices as well as ways to increase their knowledge and efficacy related to formative assessment. After all, if teachers do not feel capable of doing formative assessment it is unlikely to occur, meaning that the growth seen in this study will be a missed opportunity in mathematics classrooms.

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University–Urban High School Partnership: Math and Science Professional Learning Communities

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This study focused on science and math professional learning communities (PLCs) that were implemented through a university-urban high school partnership. These PLCs were part of mandated school-wide, content-based PLCs implemented as part of the reform efforts initiated in an urban school to address the school's failure to meet Adequate Yearly Progress (AYP) for four years consecutively and low graduation rate (less than 25%) for male students. The key issues were (a) students had continually earned low test scores; (b) there was continuous principal turnover; (c) faculty morale was at an all-time low, and the quality of teaching was very poor; and (d) the students were not effectively disciplined. The study examined the impact that university faculty-led mandated PLCs have on teachers' practices and students' learning and achievement. Analysis of data revealed practices that were effective in developing and implementing these successful math and science PLCs. Three themes emerged: ethics of care, teacher agency, and aesthetics of professional interactions. Each theme contained key features that appeared to contribute to the implementation of a successful PLC.

Background

Historically, in the U.S. education may be viewed as waves of school reforms described as having the purpose of attaining excellence in student achievement and to bridge the achievement gap between minorities and their majority counterparts (Parker & Parker, 1995). One of these reforms was the revision of high school graduation criteria, which required students to take more mathematics and science courses resulting in a higher percentage of high-school graduates completing some advanced coursework in mathematics and science (National Center for Educational Statistics [NCES], 2004). Despite the increased enrollment in advanced-level mathematics and science courses, students in the United States, in comparison with students in other countries, continue to underperform on international standardized math and science assessments (Glenn, 2000; Program for International Student Assessment, 2012). However, in the lower grades, performance in math and science on international tests has shown an upward trend (Martin, Mullis, Foy, & Stanco, 2012; National Assessment of Educational Progress [NAEP], 2013). Despite these improvements, students in urban schools, who are predominantly Black and Hispanic, still perform below their counterparts in suburban schools, who are mostly White, Asian, and Pacific Islander (Goldberger & Bayerl, 2008; NAEP, 2013).

The literature on school reform supports and encourages the use of Professional Learning Communities (PLCs) as a comprehensive reform initiative (Annenberg Institute for School Reform, 2004; Fulton & Britton, 2011). In a PLC, stakeholders (teachers, administrators, and parents) continuously seek and share learning to increase their effectiveness as they reflect on the impact of their actions with their students (Leo & Cowan, 2000).

Professional Learning Community

A growing body of literature shows that collaboration and teamwork practices within supportive PLCs have positive outcomes for teachers' professional development (Fulton & Britton, 2011). Collaboration is critical to the development of PLCs in schools. However, opportunities for teachers to interact either within or outside school have been mostly sporadic and random (Maloney & Konza, 2011). PLCs facilitate the move from the traditional view of teachers from being isolated practitioners toward a collaborative, learning-centered model (Morrissey, 2000). Studies show that PLC embedded professional development approaches are effective in improving teaching and learning processes (Hord, 2008; Lutrick & Szabo, 2012).

Five components that have been shown to be part of a successful PLC are: (a) shared values and visions, (b) shared and supportive leadership, (c) collective learning and application of learning, (d) supportive conditions, and (e) shared personal practice (Hord, 2008; Leo & Cowan, 2000). The shared values and visions involve an agreement by all stakeholders in the PLC about student needs. A

fundamental characteristic of the vision is the unwavering focus on the students' learning. The collaboration between the stakeholders' results in creative problem solving, strengthens the bond between principals and teachers, stimulates learning, and provides opportunities for teachers to grow, change, and develop professionally (Hadar & Brody, 2012). Shared and supportive leadership involves the acceptance of a collegial relationship with others in one's community. This implies an existence of shared power and decision making, which is often cited as a challenge due to the hierarchical nature of most institutions/ school districts. The literature on professional development opportunities provided through partnerships is not organized in the PLC format.

Collective learning and its application is a concept that has its origin in Senge's (1990) concept on learning organizations as places "where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together" (p. 3). Supportive conditions enable the community of learners to regularly come together as a unit for the purpose of learning, decision making, problem-solving, and doing the creative work that characterizes a PLC (Boyd, 1992; Louis & Kruse, 1995).

Peers supporting and learning from each other characterize shared personal practice. In such practice, teachers regularly visit each other's classrooms to observe and discuss their observations with the observed peer. When teachers work together, they share ideas and motivate each other and increase their content and pedagogical knowledge, which, in turn, improves students' academic achievement (Dierking & Fox, 2012). The process is enabled by the mutual respect and trustworthiness of the PLC members.

For a PLC to be effective, learning experiences must occur over a period of time, and the members must have the opportunity to reflect on the process. Loucks-Horsley, Love, Stiles, Mundry, and Hewson (2010) noted that, in the past decade, time pressures and balancing responsibilities for teachers has been a challenge to science and mathematics school reform efforts.

While there is plenty of research on professional collaborative University-School Partnerships, there is little research on mandated partnerships and the role of university content faculty members in these partnerships. In the urban school where the research was conducted, participation in the content-based PLCs was mandated. Teachers had participated in many types of reform efforts and the mandated PLC participation had the potential to be viewed by the school community as the latest "quick fix" (Dufour, 2004, 2007) to be endured. Because the mandated PLC required a partnership with the local university with content faculty members facilitating the implementation of the content-specific PLCs, the math and science PLC facilitators took into account the tension associated with the mandated PLCs.

Thus, this study examined the impact that university faculty members have on science and math teachers in mandated PLCs at an urban school. The purpose of the study was to answer the following question: What happens when science and math university faculty members facilitate a mandated school-based PLC that is aimed at changing teacher practices and improving student learning outcomes? Research on educational change/reforms, the role of change agents through reflective practice. and the ethics of care inform this research.

Methodology

Case Study Research

Qualitative case study methodology provides tools for researchers to study complex phenomena within their contexts (Baxter & Jack, 2008). According to Miles and Huberman (1994) a case is a phenomenon of some sort occurring in a bounded context. The PLCs were confined to a particular setting and situation (Clandinin & Connelly, 2000). A case study method is able to highlight teachers', students', and the university faculty members' experiences in each of the PLCs (Barone, 2009). Purposeful sampling was used in selecting the two PLCs (Bogdan & Biklen, 1998). Math or science teachers who were grouped into content-specific PLCs that had a university content-methods specialist comprised the sample.

A case study method requires the researcher to explore and describe natural settings and events (Biklen, 2011). Further, when using a case study approach, the researcher is open to investigating everything in the setting (Cronin, 2014). This study involved the exploration of a public school and events associated with two PLCs, which were considered two cases. A qualitative case study also allows the researcher to look at the specific cases in depth. According to Merriam (1998), case study methodology is utilized "because the researcher wishes to understand the particular in depth, not to find out what is generally true of many" (p. 208). The researchers took careful notes about our work with the PLC teams and recorded information for each case. For the entire intervention period, the faculty members collected data in three forms: field notes, participant observer comments, and artifacts (Bogdan &

Biklen, 1998), traditional sources of data for qualitative research (Bogdan & Biklen, 2003).

Field Notes

Each faculty member wrote detailed field notes during, and immediately after each visit with the teachers. The field notes were taken to collect details that would be missed through the use of audiotapes, such as notes on blackboards, seating arrangements, people in the room, and student actions. Also, the university faculty members wrote notes on what occurred during a meeting, interview, or any other type of session. Notes included detailed descriptions of classroom activities, reactions, actions, reflections, ideas, and hunches.

Participant Observations

Participant observations are the primary source of data for this case study. In participant observations, "social interaction occurs between the researcher and informants in the milieu of the latter, during which data are systematically and unobtrusively collected" (Taylor & Bogdan, 1984, p. 15). The university faculty members were participant observers in the weekly PLC individual and collective meetings that lasted from one hour to a maximum of four hours per week over a two-year time frame. The informants in this study were the teachers who were members of the PLC teams. The observer's notes consisted of information about specific interactions and follow-up questions that arose from these notes. These notes were collected during the weekly meetings and, following the PLC team meetings, were written in logs.

As participant observers, the faculty members served multiple roles as subject specialist assisting teachers with content and pedagogy, coteachers and teachers' assistants performing multiple roles including calling parents and guardians about their children's behavior.

Artifacts

Researchers collected artifacts created by teachers and students. These included: science laboratory forms, lesson plans, drawings created to illustrate concepts, student journals and test outcomes, and analyses of the math and science tests that the students took. Journal writing provided students with a multitude of opportunities to enhance their learning. The students were able to: (a) integrate their knowledge with their experiences to produce new learning, (b) apply theory to practice, (c) engage in critical reflection, (d) gain insight into personal development, and (e) express their feelings as they learn (Heah & Kathpalia, 2010). Each faculty member collected at least two artifacts per month.

Data Analysis

Data collection and analysis occurred concurrently with the triangulation of the three data sources occurring recursively throughout the study. Faculty members checked for consistency between data sources within and between the PLCs. For example, comparisons were done between the lessons plans teachers created with teachers' classroom practices to see if there was consistency. Faculty members used data analysis techniques such as pattern matching, linking data to propositions, explanation building, and cross-case synthesis (Yin, 2013) highlighting the convergence of in an attempt to understand the overall.

Each faculty member completed an analysis of her case study and compared the findings. Cross-comparisons of the faculty members' findings that emerged and were agreed upon are reported (Bogdan & Biklen, 1998). As Cronin (2014) observed, case study analysis involves the "gradual building of an explanation and is similar to the refining of a set of ideas" (p. 21).

Credibility and Dependability

Case study research methodology as a naturalistic approach seeks to understand phenomena in context-specific settings. Lincoln and Guba (1985) and Yin (2013) note that while reliability and validity are essential criterion for quality in quantitative paradigms, in qualitative paradigms the terms credibility, neutrality or confirmability, consistency or dependability, and applicability or transferability are to be the essential criteria for quality.

The research methodologies used provided rich data, which enhanced the credibility of the research. In addition, triangulation and analysis of data by two faculty members increased credibility. Each step of the study is provided in great detail ensuring the dependability of the study. Both faculty members agreed upon all findings reported.

Setting

The local high school at which this project was completed is a Title 1, urban school in the southeast United States that serves, on average, 614 students. The school population consisted of 98% African-American students, and 89% of students were eligible for free or reduced-cost lunch. The school faced many challenges both before and during this collaboration. It was in the process of being taken over by the state because it did not meet AYP for four consecutive years, 75% of the boys who entered the school did not graduate, and the overall graduation rate was approximately 33%. Eleven percent of students were passing physical science and algebra end-of-course (EOC) exams prior to the intervention. Other challenges that the school faced included: (a) the perceptions that the school was not a safe place to teach, (b) administrator turnover, and (c) excessive classroom management issues.

Information from guidance counselors, parent liaisons and the state report card indicated that the students faced

several challenges. A large percentage of these students lived in high-poverty contexts with an absentee parent(s) or guardian(s). Most of the parents or guardians had an inflexible work schedule, and many held multiple low-paying jobs with no benefits. Many students also worked to help to meet the family's financial needs. Few parents or guardians were able to attend parent-teacher-student conferences.

PLC Implementation and Structure

Both PLCs were single subject with all teachers per content area meeting together. The PLC meetings occurred every week for 1–2 hours one afternoon a week. After school or Saturday meetings also occurred when students needed extra help. Both PLCs had a university partner to work as a part of the team in the state-mandated reform effort to increase students' learning outcomes. Under these conditions, the teachers were reluctant to be part of the process. For the first three months, both university faculty members spent time listening to the teachers, consciously sharing with them teaching strategies and visiting the teachers' classrooms when invited. With time, more teachers invited the university faculty members to observe them. The faculty members spent time in the classrooms teaching and observing how teachers were implementing strategies developed and discussed during the PLC meetings.

Both PLCs first established a shared vision and goals. Despite the teachers' prior challenges, they were willing to commit to employing strategies that would help to improve the students' performances. They believed that the students were capable of learning math and science successfully and that they had the content and pedagogical skills to create learning environments and opportunities that would cause the learning to take place.

The process of developing the teams consisted of: (1) reviewing the students' data to determine patterns of strengths and weaknesses about the content they were to learn, (2) working with teachers on lesson planning to include specific known pedagogies and subsequently implement these practices in their classrooms, (3) identifying chosen components of the pedagogies that did not function as well as was desired and continued use of the ones that worked well, (4) working within the PLC team to select the components across the various pedagogies that were most effective and developing a highly context/content practice and then, (5) the process began again. With each iteration of the process, the teams created new materials, forms, and pedagogies that better addressed the students' needs. This strategy continuously improved and focused the teacher practices so that the students had more opportunity to learn.

Participants

The six math teachers in the department participated in the PLC. Their years of experience ranged from 5 to 46. Two of the teachers, one of whom was the head of the department, had been teaching at the school for over 30 years. Three were Visiting International Faculty (VIF). A VIF teacher is an international teacher who holds a full-time position in a school and gains firsthand knowledge of the United States, while helping to prepare students to be global citizens (VIF, 2015). All but one of the teachers had a master's degree and were categorized as highly qualified as per *No Child Left Behind Act*. All teachers teaching algebra courses for grades 9–12 participated in the study. Seven science teachers each who taught at least one section of physical science participated in this study. These teachers had experience ranging from 1 to 21 years. They had different certification routes, including the traditional route and the Program of Alternative Certification for Education (PACE), while others were VIF. One of the teachers had a master's degree and was the head of the department.

Baseline Data and Interventions

Both PLC teams analyzed data from the High School Academic Performance (HSAP) exit exam scores. Students must pass HSAP to earn a high school diploma. The science teachers used End of Course (EOC) exams. EOCs are used to assess content that is not covered by the HSAP. Both EOCs and HSAP exams are summative assessments created by the Department of Education in the State. The interim tests that were used were the Measures of Academic Progress (MAP) scores. MAP, a formative assessment, is a norm-referenced measure of student growth over time. Through the analyses of the data, the teams identified the content areas that students had difficulties and developed strategies to address students' learning difficulties and challenges.

In math, the analysis of the MAP and RIT scores showed that over 85% of the students lacked basic math skills in numbers and operations, algebra, geometry, measurement, and data analysis and probability. In addition, analysis of student performance on the HSAP exam showed that fewer than 5% of the students attempted the word problems. Additional data revealed that 89.7% of the students came to the high school with performance at or below the basic level on their eighth grade math proficiency test. Using the analysis of the RIT scores and computer-based math assessments, the math teachers and the faculty members found that the students had weaknesses in algebra and numbers and operations. To address these weaknesses, teachers selected learning materials and computerized instructional assessments as interventions.

Table 1
High School Assessment Program (HSAP) Exam Pass Rate: Second-Year Students

	Local High School Where Project Was Completed				High Schools with Similar Students			
Percent	2005	2006	2007	2008	2005	2006	2007	2008
Passed 2 subtests	32.6	47.8	55.7	55.0	53.8	57.1	61.8	64.5
Passed 1 subtest	28.7	29.6	27.9	27.1	22.8	17.0	20.8	16.0
Passed no subtests	38.7	22.6	16.4	17.8	23.3	36.7	20.9	20.1

The results show a steady increase in the number of students who passed the HSAP exam.

With the combined interventions, there was a marked increase in student content knowledge in geometry, algebra, and on the general MAP test. Student performance on the postintervention MAP test showed significant improvement in all of the content standards. Over 50% of the students had mastered the standards and needed little or no additional interventions. In addition, student scores on the HSAP exam continued to increase throughout the period when the teachers worked as a team in the PLC. The results showed a 50% improvement in the number of students who passed the HSAP exam during the duration of the PLC. See Table 1.

In science, MAP testing showed that students had difficulty in three areas: (a) focus on multiple variables included in a concept, rather than one single independent variable that can be controlled in the system; (b) had not developed strong scientific language abilities; and (c) were not able to interpret the meaning of graphs or ways to apply them. Two students scored a 40% on the pretest. Their scores ranged from 15 to 40%, with an average pre-test score of 26%. At the end of the intervention, a total of 24 students earned a score of 70% or higher on their end-of-course exam, 23 earned a score of 60–69%, and the remaining students scored in the 50% range.

In science classrooms, after a 15-week intervention period, 70–92% of students/class were passing the EOC exam. Prior to the PLC, the average pass rate was 11%. In cases where students had special needs, the PLC had a less dramatic impact but in classes with high numbers of students in special education, the pass rate of the EOC exam increased from 6 to 40–50%.

Goal Setting

Based on the analysis of the summative and formative assessment scores, the teams created goals that were much deeper than the singular state-mandated goal. The overarching goals for both teams were the development of a deeper understanding of (a) content-specific epistemology, (b) pedagogy and, (c) the culturally relevant practices that valued ways of thinking that the students bring to the learning of science and math.

Content Specific Epistemology

At the end of the first 15-week period of the intervention, teachers began talking about the epistemology of their content area. For example, one of the science teachers teaching a unit on electricity understood that the students were not doing well in their labs because they were not able to identify a single variable and test it. Because of this, the students were not developing a way to test any items on the circuit. During the discussions, it became clear that two of the teachers had the same problem as the students. The teachers were willing to reflect on their epistemology to see if it was consistent with doing science and change their misconceptions. In the case of mathematics, one teacher whose students demonstrated a deeper understanding of how to form and discern math patterns and relationships got the opportunity to explain that epistemological component of doing math.

Content Specific Pedagogy

Over a period of time, the teachers' epistemology gradually became consistent with that of science and math and began creating pedagogies consistent with the disciplines. In science, the teachers examined the artifacts that the students created (test responses, lab results, drawings, and dialogue) and developed a lab format tailored to their students. The lab format took a holistic approach, with embedded items upon which to focus, such as independent variables, specific procedures used, and generic questions. The teachers developed the generic questions into specific questions for the lab used on that day. These specific questions were used to develop procedures and to help students understand concepts such as tables, graphs, and data analysis. The format enabled the breaking of concepts into component parts, helped students to learn scientific language, and allowed for the asking of questions and development of higher-level thinking. This approach increased students' ability to interact with each other and to be cognitively engaged in the scientific

process, enabling the development of a deeper conceptual understanding rather than a simple memorization of facts. These changes were observed during classroom observations and in students' artifacts.

In math, the teachers examined the artifacts that the students created (test responses, classroom notes, reflective journals, and dialogue) and developed lessons that promoted conceptual understanding of mathematics. The focus shifted from arithmetic to doing math. For example, the teachers embedded more word problems in their lessons and provided the students with strategies that required them to apply appropriate problem solving techniques such identifying the problem, developing strategies for solving the problem (drawing pictures, charts, tables), implementing the strategies and checking their answers. The teachers began to emphasize the process rather than the final answer.

Because the teachers cared and were deeply committed to their students' learning, they planned additional time to work with their students. The math teachers planned Saturday tutoring and two high school exit exam retreats for students who were about to sit for their HSAP exams. All the students, twenty of them, six parents/guardians, guidance counselors and one administrator attended the retreat to show their support of the students and importance of the exams. Both the science and math teachers provided after school tutoring four days a week because they believed the students were capable of doing math and science but needed more time and practice than was available during regular class time.

Both PLC teams planned for peer observations and video recording of their teaching to aid in self-reflections. The following questions aided their self-reflection: (a) was my content aligned to the disciplines' epistemology, (b) did I express the content well, (c) did I teach in a manner that was consistent with my discipline, (d) how did my students respond, (e) what did my students learn, and, (f) what is my evidence of their learning?

Culturally Relevant Teaching

Both PLCs learned how to help the students code switch between their home dialect and the math and science content. For example, the students' dialect includes "is" or "is not" but not "might" or "could" (Blake & Van Sickle, 2001). This language makes understanding of hypothesis, conjectures and reasoning difficult for them (Aina, Van Sickle, & Blake, 2002). Also, the students have limited use of prepositions tending to overuse the word "by" making it nonspecific. The teachers learned to use local examples that come from the students' everyday lives. For example, when studying pressure laws in chemistry, students were asked to think of what happened to unopened potato bag in a hot car. When studying slope, we started with slope zero because our landscape is flat. In order to understand greater or less than symbols, we discussed the students' pay scales. These examples showed linkages between the context and the content they needed to learn.

Investigating the contributions of minorities in math and science was fascinating to the students. The students were surprised to find significant contributions in math and science by African Americans and other minorities. Journal writing in math and note booking in science was particularly exciting for the students because the guidelines were flexible, and creativity was allowed to demonstrate their understanding of concepts. This graded activity forced the students to revisit the content that they had learned and to write about it. Although the students disliked writing, all completed this activity. Journal writing served an unexpected purpose of promoting dialogue and rapport within the learning community, and as an avenue for the teachers, students, and the faculty members to talk about math proficiency in a nonjudgmental manner. The students talked about their challenges in math and provided the teachers with insight on how to differentiate instruction for their benefit.

Discussion

In both PLC case studies, there were changes in teacher epistemology, pedagogy, and culturally relevant practices that had a positive impact on student learning. University faculty members' participation in the PLCs enhanced teacher effectiveness in the classroom and improved student learning. Three major themes emerged from the analysis of the two case studies. The first theme is the ethics of care. The participants expressed elements of care. The second theme is teacher agency. Together, the university faculty members and the teachers in the PLCs created inquiry-based instructional materials. The third theme is aesthetics of professional interactions. The teachers within each PLC began interacting in respectful and meaningful ways. In the next section, these three major themes are described using a logic that constructs the model for university faculty members' participation in a high school PLC.

Ethics of Care

Ethics of care involves attending to the people in a certain context. As Noddings (1988) stated, "From the perspective of caring, the growth of those cared for is a matter of central importance" (p. 221). In both case studies, the university faculty members learned to listen and to discern the teachers' perspectives of their students' abilities and were able to provide the teachers with materials, practices, and ideas that had the potential to generate positive teaching and learning

outcomes. After several weeks of meetings and discussions, in each case study, a "brave" teacher would use the suggested ideas that would produce a greater number of positive results than in his/her previous practice. Eventually, different teachers had the courage to try different materials and were more successful than they previously had been. The faculty members listened to the teachers, and, subsequently, the teachers became more willing to listen to each other. This model allowed teachers to attend to each other's growth and the growth of their students. The more the teachers sought the academic growth of their students, the more the teachers sought strategies to improve their pedagogy. At this point, the teachers collaborated to create materials and opportunities that were targeted to meet their students' needs.

Appreciating the strengths of the group members. Noddings (1988) emphasizes the importance of open dialogue that is mutual and marked by reciprocity as a means to arrive at solutions to difficult problems. Once teachers began to engage in research-based practices in their classrooms and shared their students' results during the PLC, deeper conversations between team members took place. These conversations were about what worked, what did not work, and what needed to be changed. The conversations and sharing of teaching experiences helped the teachers to develop trust in each other, and they began to request their colleagues to observe them using practices that they perceived as effective. They also videotaped themselves teaching and shared the videos with each other. These peer observations enriched the conversations and became another data source about students' progress and their teaching practices. The team members' growth as effective teachers was noticeable, and their conversations were reciprocal.

Teacher Agency

Understanding one's position. University faculty members took the position that the members of the PLC have the ability to effect change or act as a change agent. Gardiner defines an agent as "someone who is contemplating an action, has already acted, or is presently acting" (cited in Bartky, 1995, p. 178). Once the teachers were successful, they began to demonstrate these characteristics. Through asking questions of the teachers and expecting explicit answers, teachers developed the capacity to determine and act as agents/knowers, not only in their classrooms but also in their PLC. This knowledge allowed the teachers to restructure their thinking about their ability to cause change. Through listening and observing, the teachers were able to discern their students' competencies that were not measurable on standardized tests. They began to target the components of the standardized tests that the students needed to be competent. This process is what Schön (1991) refers to as reflective practice. Teachers recognized that every classroom was different and "that strategies must constantly be changed, invented, reconceptualized to address each new teaching experience" (Hooks, 1994, pp. 11–12).

Exploring the possibilities within one's position. Schön (2001) notes that, "when a practitioner sets a problem . . . he names the objects of this attention and frames them in an appreciative context which sets a direction for action" (p. 7). The teachers, in exploring the possibilities of their new position within the PLCs, began to voice their concerns with the rest of the PLC participants and were able to develop a constructive dialogue. In addition, teachers became more comfortable and began to develop their agency in both PLCs. Out of that teacher agency, some took leadership roles within their corresponding PLCs and others became more comfortable receiving advice from both the faculty members and the lead teacher(s).

Making change a possibility and engaging in reflective practice. The researchers facilitated opportunities for the teachers to become agents of change by encouraging and creating reflective practitioner opportunities. The teachers took responsibility for their own learning (professional development or pedagogical knowledge) as well as for student learning. These characteristics of a reflective practitioner contribute to effective leadership and are a major component of change.

Collaboration between teachers was further promoted by the sharing of teaching videos. Faculty members shared videos of themselves' teaching, and encouraged teachers to videotape and reflect on their teaching practices. Through watching their videos, teachers obtained peer feedback and self-analysis. The teachers not only identified and reduced habits that minimized their effectiveness, but, more importantly, they also recognized and supported those habits that maximized their teaching success (Osterman, 1990).

Aesthetics of Professional Interactions

Mutual vulnerability. Hooks (1994) states, "Empowerment cannot happen if we refuse to be vulnerable while encouraging students to take risks" (p. 21). All members of the PLC showed their vulnerability. Mutual vulnerability was crucial to creating a reciprocal relationship between teachers, students, and faculty members. The faculty members demonstrated their vulnerabilities by modeling the strategies that were developed through the PLCs in the teachers' classrooms. The teachers saw the instances when the faculty members were successful at teaching and instances when they were

not. This encouraged the teachers to take risks by implementing new strategies with their students. This mutual vulnerability not only provides for an environment in which its participants grow but also aids in creating teacher empowerment and agency (Hooks, 1994).

Tactful interactions related to solutions. Because the teachers were aware that the school was at risk of state takeover and had experienced interventions by other outside parties, the thoughtfulness and tact on the part of the faculty members became important characteristics. The phenomenology of thoughtfulness and tact opened doors for relationships in settings otherwise predisposed to complicated interactions (van Manen, 2007).

Conclusion

The university faculty members played an important role in facilitating the development of the five key components of a successful PLC: (a) shared values and mission, (b) shared and supportive leadership, (c) collective learning and its application, (d) supportive conditions, and (e) shared personal practice. Of equal importance was the manner in which the enactment of these key components was negotiated in each PLC and the role that the university faculty member played in facilitating these negotiations. The university faculty initiated compensatory approaches that were constantly focusing on the shared vision and values, which were coupled with the strong belief in the students' ability to learn as a central focus of the entire process.

Space was created for the participants of the PLCs to hear each other, reflect, and make decisions on classroom practices that worked in their context. At the beginning of the study, the PLC lacked all five components of a successful PLC. The teachers were frustrated by the top-down approach of the school's administration. The university faculty members instituted a different leadership style, one that incorporated the shared leadership component. The PLC did not have a shared vision or goal prior to the university faculty members' intervention, and there was no collaborative effort within the group. The combination of the three tenets enacted consistently over time by the university faculty members produced a successful PLC.

The teachers' collective learning and application of learning contributed to positive results with the students as observed in the classroom. These results reinforced teachers' confidence and leadership skills within the PLCs and in their classrooms. Teachers' willingness to discuss their successes and failures within their pedagogy exposed their mutual vulnerabilities, which seemed to increase the teachers' trust for each other and to build stronger relationships with each other as they engaged in becoming agents of change. The teachers' practices improvement correlated with students' learning and achievement.

Limitations of the Study

A major limitation of this study was that this PLC was state mandated. The circumstances under which these PLCs were implemented were unlike many reported in other studies of PLCs.

Implications of the Study

The results indicate that, while the development of the five components of a PLC is important, each PLC is unique. Conditions must be created through which the team members can individually and collectively make decisions that empower them to become agents of change. The presence of a faculty member as a subject specialist mandated PLCs, can facilitate the negotiations that take place within the PLC. These negotiations stimulate the development of the five components of a successful PLC discussed earlier. The involvement of faculty members in PLCs also can initiate the development of a positive dynamic that motivates PLC members to begin the process of positioning themselves as agents of change. University faculty members can serve as a catalyst to change and enhance the likelihood of success in PLCs.

The three themes of ethics of care, teacher agency, and aesthetics of professional interactions were manifested as a result of the presence of a university faculty member. An external person can ensure that these negotiations occur and can facilitate the discussion of difficult issues. These interactions enabled the teachers to enact pedagogies in their classrooms that generated positive change.

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Authors' Note

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Students' and Teachers' Conceptual Metaphors for Mathematical Problem Solving

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Metaphors are regularly used by mathematics teachers to relate difficult or complex concepts in classrooms. A complex topic of concern in mathematics education, and most STEM-based education classes, is problem solving. This study identified how students and teachers contextualize mathematical problem solving through their choice of metaphors. Twenty-two high-school student and six teacher interviews demonstrated a rich foundation for these shared experiences by identifying the conceptual metaphors. This mixed-methods approach qualitatively identified conceptual metaphors via interpretive phenomenology and then quantitatively analyzed the frequency and popularity of the metaphors to explore whether a coherent metaphorical system exists with teachers and students. This study identified the existence of a set of metaphors that describe how multiple classrooms of geometry students and teachers make sense of mathematical problem solving. Moreover, this study determined that the most popular metaphors for problem solving were shared by both students and teachers. The existence of a coherent set of metaphors for problem solving creates a discursive space for teachers to converse with students about problem solving concretely. Moreover, the methodology provides a means to address other complex concepts in STEM education fields that revolve around experiential understanding.

In the last 60 years, mathematics educators have perceived mathematical problem solving as a heuristic process (Pólya, 1945), a logic-based program (Newell & Simon, 1972), a means of inductive and deductive discovery (Lakatos, 1976), a framework for goal-oriented decision making (Schoenfeld, 1985, 2010), methodologies with multiple variables (Kilpatrick, 2004), a standard (NCTM, 1989), and a model-eliciting activity (Lesh & Zawojewski, 2007). In their historical analysis of problem solving, Stanic and Kilpatrick (1989) state, "The term *problem solving* has become a slogan encompassing different views of what education is, of what schooling is, of what mathematics is, and of why we should teach mathematics in general and problem solving in particular" (p. 1). Consequently, definitions of problem solving can be nebulous, or downright conflicting (Schoenfeld, 1992). As Shumway (1982) states, "We (researchers of problem solving) don't know what problem solving is, but if you read our definitions you'll know what it isn't" (p. 131).

Despite these varying perspectives on problem solving, students are told problem-solving skills are vital for their secondary mathematics education (NCTM, 2000; NGA & CCSSO, 2010). Secondary school teachers have significant influence over students' perception of problem solving (Pólya, 1945; Schoenfeld, 1985). To communicate in a language that is meaningful to the student, it has been suggested that a teacher could start with the student's contextualization of problem solving rather than assuming the student shares the teacher's meaning of mathematical problem solving (Sakshaug & Wohlhuter, 2010). However, current research lacks a means to tap into students' experiences that generate students' contextualization of problem solving.

The goal of this study is to understand secondary students' and teachers' contextualization of mathematical problem solving. Understanding how students and teachers contextualize problem solving can give researchers and practitioners a concrete starting point from which to generate productive discourse about problem solving, despite the cacophony of definitions. Accomplishing this feat requires significant focus on the language and experiences of students and teachers. Students rely on their experiences to make sense of mathematical concepts. With problem solving, the experiential complexity stems from interpretation and communication (Pólya, 1945). To align the researcher's interpretation with the student's and teacher's experiential perception, the linguistic tool of metaphor is ideal (Sfard, 1998, 2000) because metaphors allow people to relate experiences for communication and cognition (Presmeg, 1997). To identify how secondary students and teachers contextualize mathematical problem solving, this interdisciplinary study answers the following questions:

> Q1: What metaphors do secondary students and teachers use to describe their experiences with mathematical problem solving?
> Q2: Is there a coherent subset of these identified metaphors that can inform research on how students and teachers perceive problem solving?

To answer these questions, this study collected data from seven high school geometry classes via 28 student and teacher interviews. Each interview had students or teachers express their perceptions of a specific mathematics problem from a common assessment. The data were analyzed using a mixed methods design incorporating Conceptual Metaphor Theory (CMT, Lakoff & Johnson, 1980). A qualitative phenomenological analysis identified the conceptual metaphors used by students and teachers for mathematical problem solving. A quantitative analysis used the qualitatively identified conceptual metaphors to determine the existence of a coherent subset of metaphors via frequency and popularity. This study found that such a coherent subset of metaphors existed and had significant overlap between teachers and students. As a result, this study posits that identifying coherent metaphors can concretize (Danesi, 2007) problem-solving discourse between students and teachers. This study offers a working set of conceptual metaphors for mathematical problem solving to help teachers and researchers practice mathematical discourse (Moschkovich, 2007) with students.

Framework

Mathematical Problem Solving

To answer the research questions, we need to be able to interpret the students' perception of problem solving. Students' conceptual understanding of problem solving should be at the center of all interpretations and applications of problem solving (NCTM, 1989, 2000; Schoenfeld, 1985). Without knowing the student's perception of problem solving, one cannot be sure the teacher's interpretation aligns with the student's perception. Silver (1985) writes:

> In order to give a richer characterization of mathematical problem solving, we must go beyond process-sequence strings and coded protocols. And we need also to go beyond simple procedure-based computer models of performance. We need to develop new techniques for describing problem-solving behavior not only in terms of the procedures utilized but also in terms of the conceptual systems that influence performance. The successful implementation of rigorous modeling techniques of this type would give us more powerful models of problem-solving performance and might provide more suitable models for learning, since they could account for the phenomena of cognitive restructuring and conceptual reorganization that are observed as people learn in complex domains. (p. 258)

This study strives to identify such a cohesive conceptual model that will allow for "cognitive restructuring" and "conceptual reorganization" (p. 258). Such a model aligns with the framework of a cognitively embodied mathematics (Lakoff & Núñez, 2000) because students' understanding of mathematics is embedded within their mathematical experiences (Núñez, 2008). Hence embodied cognition mandates a substructure, a conceptual system (Silver, 1985), to describe and identify students' mathematical problem-solving experiences.

Identifying said experiences is complex for research because of the layered mediums through which this communication takes place. Steffe (1983) reminds us that the experience of the student is expressed by the student, interpreted by the researcher, related via the researcher's experience, and then expressed by the researcher. To minimize misinterpreting students' perceptions of problem solving requires hermeneutic and epistemological clarification of how the researcher will discuss mathematical problem solving.

Hermeneutically, while we cannot assume a definition of problem solving within this framework, we can define a mathematical problem. Pólya (1945) demonstrated the need to separate mathematical exercises from problems by demonstrating how problems require multiple heuristics (i.e., methods of discovery, p. 112) while exercises did not. Mayer (1998) described this distinction between "routine problems" (exercises or problems students have seen before) and "non-routine problems" (problems students have not seen before). Nonroutine problems require heuristics such as association, abstraction, comprehension, synthesis, and generalization which have been theoretically framed as metacognition (Schoenfeld, 1992). This study defines mathematical problems within the frame of Pólya (1945), Mayer (1998), and Schoenfeld (1992) where a mathematical problem requires selecting appropriate heuristics and not directly applying a previously recognized single procedure. This definition of problem emphasizes the need for clear mathematical discourse as a means to directly recognize which heuristics students select for specific problems.

Mathematical Discourse

The epistemological perspectives of mathematical discourse vary significantly. Pólya (1945) described thinking in problem solving as "mental discourse" (p. 133) with oneself. Moschkovich (2007) argued that discursive practices involve more than language, but perspectives and conceptual knowledge. Many discourse theorists agree that

communication is sufficient for constructing and sharing knowledge (Herbel-Eisenmann & Cirillo, 2009; Moschkovich, 2007), but Sfard (1998, 2000, 2009) claims it is also necessary. Sfard (2000) states "Effective communication is not *explained by* the fact that interlocutors have the same meanings (or 'shared conceptions') but rather *defines* the situation of two persons' 'having the same meaning'" (p. 300). Sfard is arguing that problem solving depends upon the participants and their shared experiences. Indeed, Cozza and Oreshkina (2013) found students' metacognitive meaning of problem-solving stemmed from collaborative cyclical discourse patterns of exploration and implementation with each other.

Fundamentally, this study's hermeneutic and epistemological framework aligns with Sfard's (2009) work on cognitive discourse because of the focus on shared experiences. Despite all the mediums through which one must interpret student and teacher perceptions of mathematical problem solving, the student and teacher are trying to communicate their personal experiences through a set of presumed shared experiences. Shared experiences are fundamental because the assumption of what students and teachers perceive as shared experiences define their interpretation of problem solving and how communication is demonstrated in the classroom.

Discourse Analysis via Conceptual Metaphors

The shared experiences expressed through discourse are interpreted and communicated through the use of metaphors (Kövecses & Benczes, 2010). Presmeg (1997) reminds us that the Greek word, *metaphora*, means to transfer or carry over. The influence of this transfer from a cognitive perspective encouraged Lakoff and Johnson (1980) to expand on Reddy's (1979) idea of the conduit metaphor to create the conceptual metaphor. In the conceptual metaphor, the literal relationship between figures of speech is replaced with a conceptual mapping between linguistic expressions (Lakoff, 1993). For example the literal metaphor, "Your theoretical framework lacks a solid foundation" would have the conceptual metaphor THEORIES ARE BUILDINGS[1] attached to it. Thus with each metaphor, two concepts are connected:

> Literal Metaphor: The actual literal expression.
> Conceptual Metaphor: TARGET DOMAIN IS SOURCE DOMAIN

[1]Lakoff and Johnson (1980) used capital letters to delineate the literal and conceptual metaphors more easily, this paper will follow the same format.

In all conceptual metaphors, there is a source domain and a target domain. The source domain is the experientially known domain and the related concept is the target domain. In the metaphorical linguistic expression "The solution escapes me," the target domain is solutions while the source domain is prey. Hence the conceptual metaphor is SOLUTIONS ARE PREY. It is important to note that despite the use of the being verb "ARE," the phrase is unidirectional (TARGET DOMAIN → SOURCE DOMAIN).

Cognitive linguists typically classify these conceptual metaphors into three hierarchal categories: structural, ontological, and orientational (Kövecses & Benczes, 2010; Lakoff & Johnson, 1980). Structural metaphors strive to describe a complex concept, such as time, in terms of a concrete experiential object, such as a limited resource, i.e., "Don't waste my time." Ontological metaphors provide target domains with less structure and a new reality in which they may be defined. Personification is regularly ontological, as in the phrase "the solution escapes me." Orientational metaphors are the most difficult to relate experientially according to linguists (Kövecses & Benczes, 2010). They are broad concepts with only a specific direction inherent in human development. The metaphorical expressions "things are looking up for him" and "he fell ill" are examples of the conceptual metaphor HEALTHY IS UP. These categories of conceptual metaphors (Structural, Ontological, and Orientational) are used to map the communicative and cognitive nature of a person's experiences (Lakoff & Johnson, 1980).

Mathematics teachers and students share an experiential set: solving mathematics problems. However, students' and teachers' strategies for solving a mathematical problem can vary (Lakatos, 1976; Lesh & Zawojewski, 2007; Schoenfeld, 1992). Metaphors are culturally designed to articulate these implicit perspectives. As conceptual metaphors have been used to foster cognition in mathematical problem solving (Lakoff & Núñez, 2000; Sfard, 1998), this study will use conceptual metaphor theory (CMT) to answer our first research question, Q1.

CMT in Practice

CMT was introduced by Lakoff and Johnson in 1980 and has burgeoned in many fields such as linguistics, cognitive science, psychology, education, and neuroscience (Lakoff, 2008). In CMT analysis, the researcher interprets the student model through the mapping of the conceptual metaphor. Prus-Wisniowska (1995) used this method qualitatively to interpret six undergraduate students' use of metaphors with the concept of mathematical limits. Danesi's (2003) applied CMT to mathematics education as

a means to help in understanding concretization, putting intangible terms into experiential terms:

> An abstract concept in CMT is defined simply as a "mapping" or an "extension" of one domain onto the other. This theory suggests that abstract concepts are formed systematically through such extensions and that specific metaphors are traces to the target and source domains. (p. 228)

This mapping of concepts emphasizes the epistemic view of learning as participatory (Sfard, 1998) because it focuses on the metaphors as conduits for communication (Reddy, 1979). Danesi (2007) used CMT analysis on eighth grader's perspectives of mathematical word problems and found that their ability to concretize time according to the source domain of a line, hence the *time line* and the conceptual metaphor of TIME IS A LINE was helpful with basic algebra if diagrammed. However, none of these aforementioned studies have been able to take the CMT's qualitative method and quantitatively determine a coherent set of shared experiences for a given population using coherence, which is the purpose of this study.

To summarize, mathematical problem solving is a complex topic in mathematics education and difficult to concretize. However, cognitively embodied mathematics (Lakoff & Núñez, 2000) requires educators to question how students and teachers contextualize and conceptualize problem solving if mathematical discourse is allowed to help students share and construct meaning (Moschkovich, 2007; Sfard, 2000). Thus there needs to be a model (Lesh & Zawojewski, 2007) that identifies the student's and teacher's shared and personal experiences of mathematical problem solving. This interdisciplinary study will construct such a model using CMT analysis (answering Q1) and then determine if a subset of problem-solving metaphors exist for students, teachers, or both students and teachers (answering Q2).

Method

Initially, a pilot study (Yee & Bostic, 2012) interviewed nine high school students and asked them to describe their problem-solving techniques with three distinct problems (Yee, 2013). The data were analyzed using CMT analysis. The results of the pilot study demonstrated rich structural, ontological, and orientational metaphors students associated with mathematical problem solving (Yee & Bostic, 2014). The pilot study was the foundation for this study.

Participants

This study took place at a suburban high school with geometry students and teachers. These geometry classes were chosen because the culture encouraged students to justify their conclusions, which was helpful in being thorough in the interview process. Two teachers (Alpha and Beta) and 22 ninth- and tenth-grade students volunteered to participate in the study.

Design

Together, teachers Alpha and Beta designed three common assessments. The researcher individually interviewed Alpha, Beta, and all participating students during the first three common assessments of the geometry course. Alpha and Beta were each interviewed three times, once with each common assessment. Hence there were six teacher interviews and 22 student interviews in total. All participants met with the researcher individually for a 15–20-minute video interview. While classroom and group discussions could yield valuable conceptual metaphors as well, such conversations would implicate too many variables (i.e., who owned which metaphor) for the primary purpose of this study. Student interviews focused on one problem from the common assessment that each student had already completed (Figure 1).

Researchers selected problems from the teacher-designed common assessments that offered significant discussion of their techniques. All three problems were nonroutine (Mayer, 1998) because both teachers had not used similar problems in homework or classroom exercises and thus no single, direct strategy had been shared. For example, in Common Assessment 3, students had learned the multiple methods of identifying if two triangles were similar, but the ideal technique was not directed in the instructions. Of the three common assessments, seven students were interviewed for Common Assessments, 1 and 2, while eight students were interviewed for Common Assessment 3. Thus, there was a balanced distribution among geometry students.

Data Collection

To make sure the researcher could ask clarifying questions to properly identify students' metaphors, a semistructured interview method was used (Table 1). Students had already taken the selected common assessments and had access to their previous work on the assessment during the interview. Researchers watched the video and transcribed all conversations.

After collecting data, the researcher: (1) qualitatively coded the audio and video data using CMT analysis to determine which source domains students and teachers associated with the target domain of problem solving and

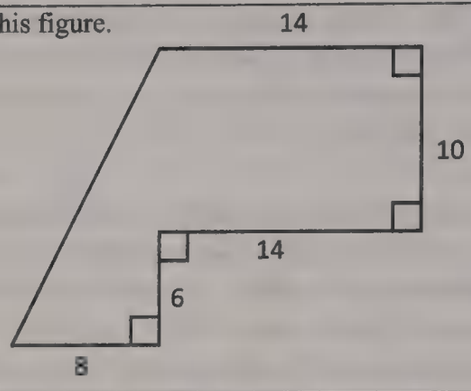
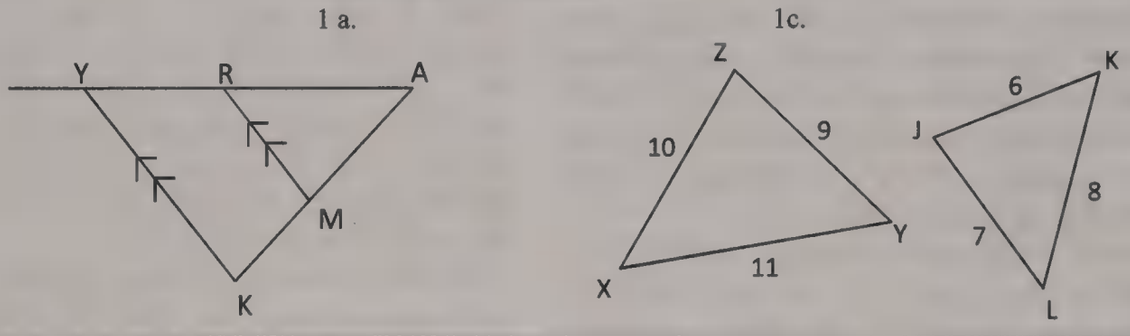
Common Assessment	Question #	Problem
1	5	A regular hexagon has rotational symmetry about its center. What is the minimum number of degrees of rotation necessary to show rotational symmetry? Explain your reasoning using math vocabulary. (No picture included)
2	7	Find the **area** and **perimeter** of this figure. 
3	1a and 1c	Determine whether or not each pair of triangles is similar. Justify each by using a flowchart. 

Figure 1. Questions from the first three honors geometry common assessments.

(2) quantitatively analyzed the frequency and popularity of each source domain to determine which source domains significantly describe mathematical problem solving.

Qualitative Analysis

When using CMT analysis, each literal and conceptual metaphor was identified and categorized via cognitive function (structural, ontological, or orientational). The categories were not preconstructed, but did phenomenologically interpret (Eatough & Smith, 2008) students' and teachers' literal metaphors. The following conceptual metaphor analyses have been shared as prototypical examples clarifying the interpretative design of CMT to offer insight into how student and teacher experiences can be interpreted from their discursive and experiential use of problem solving.

Problem solving is a journey. Students and teachers used the source domain of journey pervasively as a structural metaphor throughout the interviews. Penelope stated that to solve the problem she "followed the directions," the act of following adds structure in her approach to problem solving. Oliver's statement, "I don't know, that wouldn't have gotten me too far," refers to distance from the solution, indicating that the theme involved is traveling to the solution, i.e., the journey. Phil

Table 1
Semi-structured Interview Questions for Teachers and Students

Teacher Interview Questions	Student Interview Questions
How will students perceive the mathematical problem?	How did you perceive the mathematical problem?
Why do you think students will perceive the problem the way you have described it?	What does it mean to solve the problem?
How will students solve the problem?	How did you solve the problem?
Why will students solve the problem that way?	Why did you solve the problem that way?
Could students solve the problem differently?	Could you have solved the problem differently?
What possible problem solving techniques do you see students using to solve this problem?	

referenced reflection, an important aspect of problem solving (Pólya, 1945) by stating, "when I look back at what I did, I kind of think I might have gotten it mixed up with something else." The action of looking back (as opposed to looking forward) is a context generated to express where one has been on a journey. Beta also uses the structure of a journey when students solve problems because they will have to "use the short cut conjectures that we've talked about," and Alpha discusses that for one problem "there is not really more than one way to go about it." Thus, we see that students and teachers are regularly drawing on the structure of journey to contextualize problem solving.

Problem solving is a race. While students and teachers used multiple source domains for problem solving, the teacher Beta regularly referenced the structural metaphor PROBLEM SOLVING IS A RACE. Beta used statements such as "the biggest hurdle that I think that they might run into is" and "that is a tough hurdle for a lot of the kids." Beta used the word "run" referencing a fast-paced journey such as a race. Hurdles are iconic of races, thus corroborating the experiential association with races. This is further confirmed when Beta states, "It's one thing that I think might trip up a few students or might at least at the beginning." When one is tripped up at the beginning of a race, they may or may not be able to continue. However, this metaphor references a shared experience of the source and target domain, "the beginning." When Beta states "at least at the beginning" he is implying that the beginning is not the end of the problem-solving technique, thus implying that the hurdle, or the object that trips up the student, impedes the student but does not terminate their efforts.

While Beta was unaware that he was using such metaphors, these metaphors carry significant entailments (Lakoff & Johnson, 1980) for students who presume that problem solving is a race. Specifically, students may identify that the speed at which one solves a problem is more significant than the quality or understanding of the problem. Additionally, the metaphor of race may entail the need for competition, to finish the test in a speedy fashion as a measure of intelligence. Fundamentally, there seem to be significant sociomathematical norms (Yackel & Cobb, 1996) involved with the choice of metaphors of the teacher. These discursive norms can influence students' structural conceptions of problem solving (Sfard, 2000).

Problem solving is discovery. A verb that both students and teachers used regularly was "realize." Ken states, "I knew that was going to be important because when two lines were parallel you can realize what angles are similar and stuff." Additionally, Zandra stated that, "when I was using my other method I kind of realized that that was completely off because it was over 90 degrees." Teacher Alpha states, "They need to realize that this is not going to be part of the perimeter" and Beta states, "I think the first thing that students have to realize about part (a) is some will look at that and will not really see that there are two triangles there."

The word "realize" represents an action by the students that will make them aware of important information. Merriam-Webster Dictionary (2014) defines discovery as "to make known or visible," which is how students and teachers are using the word realize. Thinking of problem solving as a discovery redefines what constitutes solving without adding a firm experiential structure, unlike journey. When thinking of problem solving as a journey, there is a destination a priori. However, discovery lacks this structure because one does not know what one is to discover. Thus, discovery offers a varying ontological perspective on problem solving because discovery offers some structure, but changes the reality of the solution.

Problem solving is building. Both students and teachers referred to the structural metaphor relating problem solving to building, aligning with constructivist approaches to learning. For example, Oscar referred to the cognitive aspect of problem solving when saying, "I put all those components together to create one big complex thought." The teachers used the building metaphor in discussing how the students learned through inductive reasoning. Beta stated, "We tried to build up the pattern showing them what's the degree of rotation of an equilateral triangle." Adison also expressed the building metaphor when stating, "They know they need to set up a flowchart" because setting up references the foundation with the orientation of up. Building was also referenced by teachers and students using the verb "made." Erik stated, "You probably could have made it like a trapezoid I guess." Oliver described, "It made it a lot more organized than stating facts randomly all over." Zach admitted, "I just did make like, little mistakes." The action of "making" was a regular reoccurrence of solving problems.

Problem solving is a process. Teachers and students frequently referred to solving problems as a process, structurally emphasizing *how* one solves problems. Moreover, students and teachers literally referenced the word process while describing problem solving. Phil stated, "I had a different thought process and I'm kind of thinking that these can't equal 360." Phil perceives problem solving as a cognitive process, yet recognizes that there are multiple processes. Rhonda referred to her "automatic brain" that helped her "find the process then find the solution." Rhonda

continued by saying, "once you got the solution you just write down your process. Teachers always want the process." Rhonda's automatic brain is an enlightening illustration of the utility of the process metaphor. Her perspective on teachers always wanting to see a process suggests an emphasis on the "how" in her geometry classroom.

Teachers also referred to problem solving as a cognitive process. Alpha pointed to the student's cognitive use of problem solving as a process when she stated, "It's also them understanding what notation is there but what notation they need to use to explain their thought process." Similarly Beta refers to a specific problem-solving process when he states, "I think that they're a little bit more comfortable with the flowchart process and they know to get right into the geometry part." The flowchart process is a variation on two-column proofs (Dietiker, Kysh, Hoey, & Sallee, 2007). Teachers regularly referenced the "process" as the "how" of problem solving for tangible assessment of student performance. Both teachers demonstrated the "process" through the form of a procedural source domain. The procedural perspective of problem solving viably addresses the "how" within the problem solving, but omits the "why" behind the process.

Quantitative Analysis

From the qualitative analysis of 22 student interviews and six teacher interviews, this study analyzed students' scores (according to their teacher's rubric), students' and teachers' structural conceptual metaphors, ontological conceptual metaphors, orientational conceptual metaphors, total source domains (per participant), and different source domains (per participant). Student and teacher source domains associated with the target domain of problem solving were then tallied in two different ways. The total for each source domain was referenced as the *frequency* of a source domain. However, the total number of times a source domain was used (frequency) may not demonstrate how pervasive the source domain was among all students. For example, it may be the case that Evan used PROBLEM SOLVING IS A JOURNEY enough times in his interview to compensate for another student not using the journey source domain at all. Thus for internal validity, the source domains were also analyzed for *popularity*, the number of students who used the metaphor. With popularity, if any student or teacher used PROBLEM SOLVING IS A JOURNEY during his/her interview, it was only recorded as "used" for that student. Together, these two quantitative analyses determined if a metaphorical system (Kövecses & Benczes, 2010) existed by comparing each source domain's frequency and popularity between teachers and students. Teachers' perceptions of student problem solving using conceptual metaphors were compared to students' perceptions of mathematical problem solving to identify similarities and differences.

Results

Qualitative Results

CMT analysis illuminated relationships between teacher and student thinking about problem solving. Figure 2

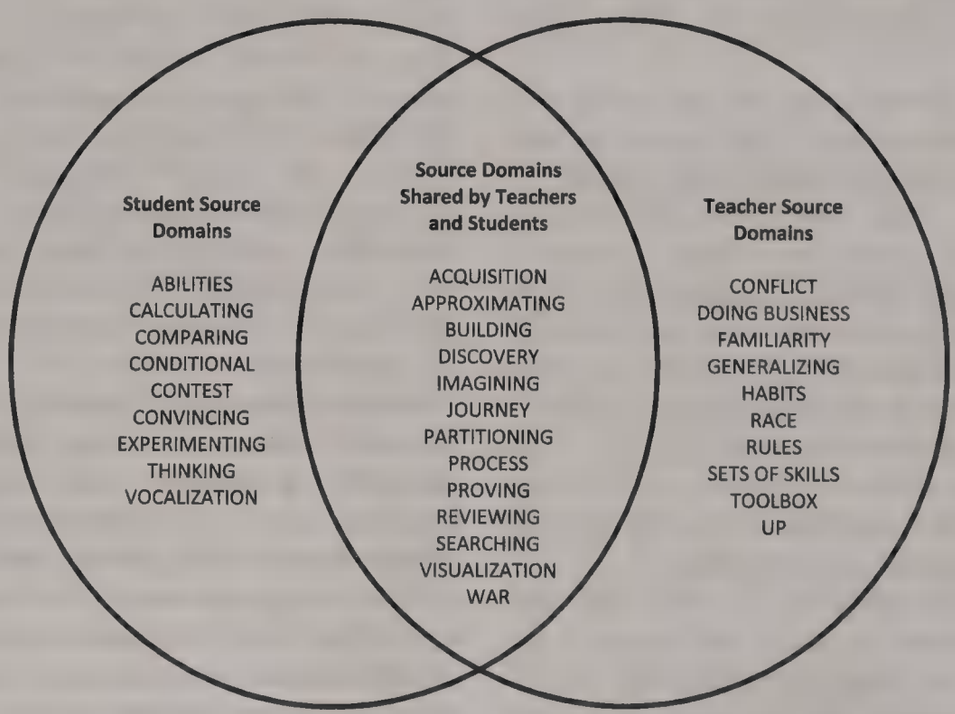


Figure 2. Venn diagram of problem solving source domains for teachers and students.

Table 2
Descriptive Statistics of Students' Conceptual Metaphors for Problem Solving

	N	Minimum	Maximum	Mean	Standard Deviation
STUDENT INTERVIEWS					
Score	22	50%	100%	76.2%	18.5%
Structural Metaphors	22	8	45	17.55	9.10
Ontological Metaphors	22	0	18	5.91	5.15
Orientational Metaphors	22	0	3	0.59	1.01
Total Source Domains	22	5	53	19.14	10.72
Different Source Domains	22	3	9	6.27	1.52
TEACHER INTERVIEWS					
Structural Metaphors	6	12	33	22.17	8.28
Ontological Metaphors	6	6	10	7.67	1.97
Orientational Metaphors	6	0	1	0.167	0.41
Total Source Domains	6	11	39	26.17	10.53
Different Source Domains	6	1	10	7.83	2.40

illustrates the source domains used by students, teachers, and both parties.

Figure 2 shows that teachers used one more source domain than the students associated with the target domain of problem solving. It is important to note that there are slightly more source domains that are shared by the students and teachers than there are exclusive to students or exclusive to teachers.

Quantitative Results

This study coded 157 conceptual metaphors of teachers and 421 conceptual metaphors of students that were associated with problem solving. Table 2 gives the descriptive statistics for the source domains relative to student and teacher interviews. Notice that the average score of the questions chosen for this study (assessed by the respective teacher) was 76.2%. This aligns with a grade letter of C which is what the teachers strove to have as the average.

The average number of conceptual metaphors categorized by cognitive function was consistent with linguistics research (Kövecses & Benczes, 2010) because Table 2 shows that structural metaphors occurred the most often (student $M = 17.55$ $SD = 9.10$, teacher $M = 22.17$ $SD = 8.28$), then ontological metaphors (student $M = 5.91$ $SD = 5.15$, teacher $M = 7.67$ $SD = 1.97$), then orientational metaphors (student $M = .59$ $SD = 1.01$, teacher $M = .167$ $SD = .41$). This corroborates the framework that students

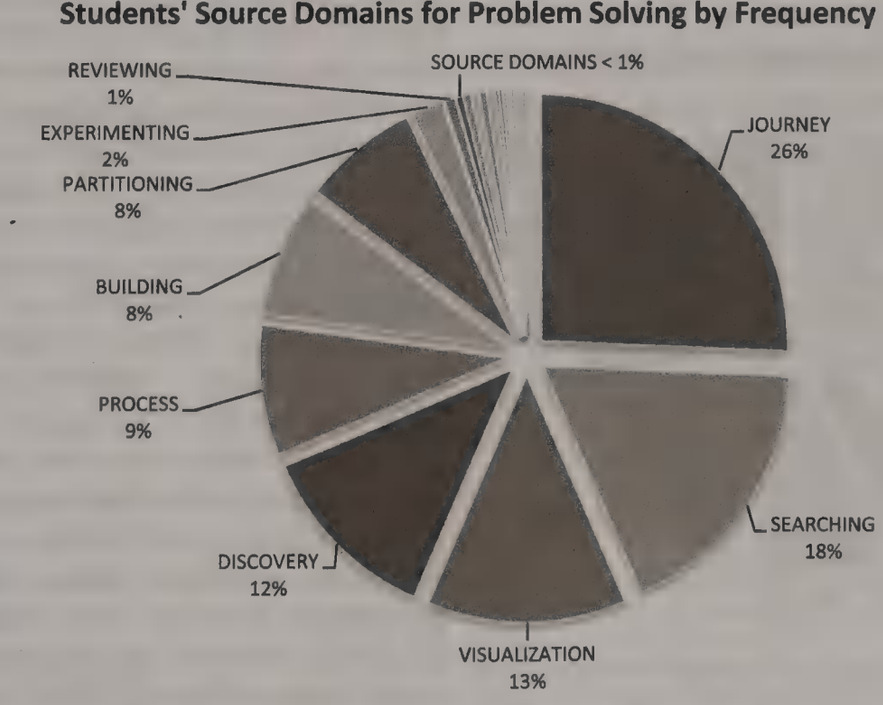


Figure 3. Frequency of students' source domains mapped from the source of mathematical problem solving. All source domains less than 1% were not shown.

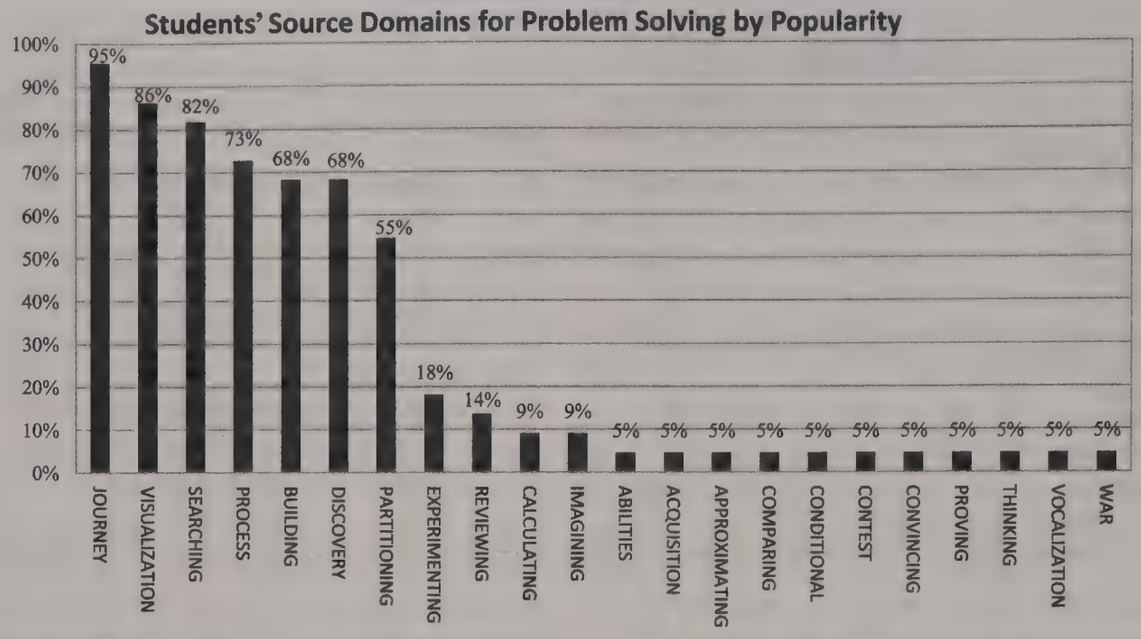


Figure 4. Percentage of students (22 total) that used each source domain mapped from the source of mathematical problem solving.

and teachers prefer to talk about problem solving with more structured and concrete experiences.

On average students used 19.14 source domains and 6.27 different source domains per interview associated with mathematical problem solving. Teachers used more conceptual metaphors than students with 26.17 source domains per interview and 7.83 different source domains. While the interviews were kept to approximately the same length for students and teachers, this illustrates that teachers referenced more metaphors and more diverse metaphors more often than students in their interviews on constructing and assessing student understanding of problem solving with the selected common assessments.

To better understand the descriptive statistics of student source domains relative to the target domain of problem solving, Figure 3 demonstrates the frequency of each source domain used by all students and Figure 4 demonstrates how popular each source domain was with students.

When comparing Figures 3 and 4, there is agreement in the most frequented and most popular source domains used by students associated with the target domain of problem solving: JOURNEY, SEARCHING, VISUALIZATION, DISCOVERY, PROCESS, BUILDING, PARTITIONING, EXPERIMENTING, and REVIEWING.

The process was repeated with teacher source domains. Figure 5 demonstrates the frequency of each source domain used by all students and Figure 6 demonstrates how popular each source domain was with students.

When comparing Figures 5 and 6, there was agreement in the most frequented and most popular source domains used by teachers associated with the target domain of problem solving: JOURNEY, DISCOVERY, BUILDING, VISUALIZATION, PARTITIONING, SEARCHING, PROCESS, and SETS OF SKILLS.

Comparing the most frequented and most popular source domains of both students and teachers yielded a coherent set of source domains to contextualize problem solving. Table 3 lists these overlapped source domains and provides prototypical examples. It is important to note that JOURNEY was the most frequented and most popular source domain referenced, while the order of the remaining top source domains varied between participants.

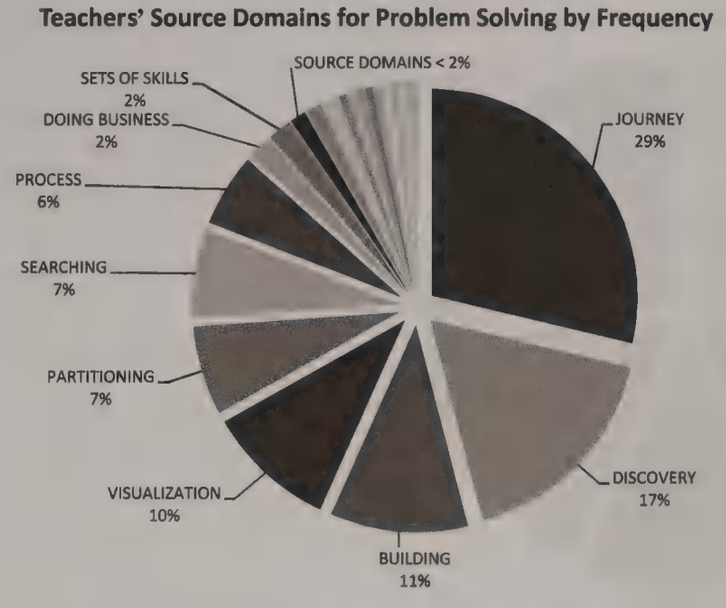


Figure 5. Frequency of teachers' source domains mapped from the source of mathematical problem solving. All source domains less than 1% were not shown.

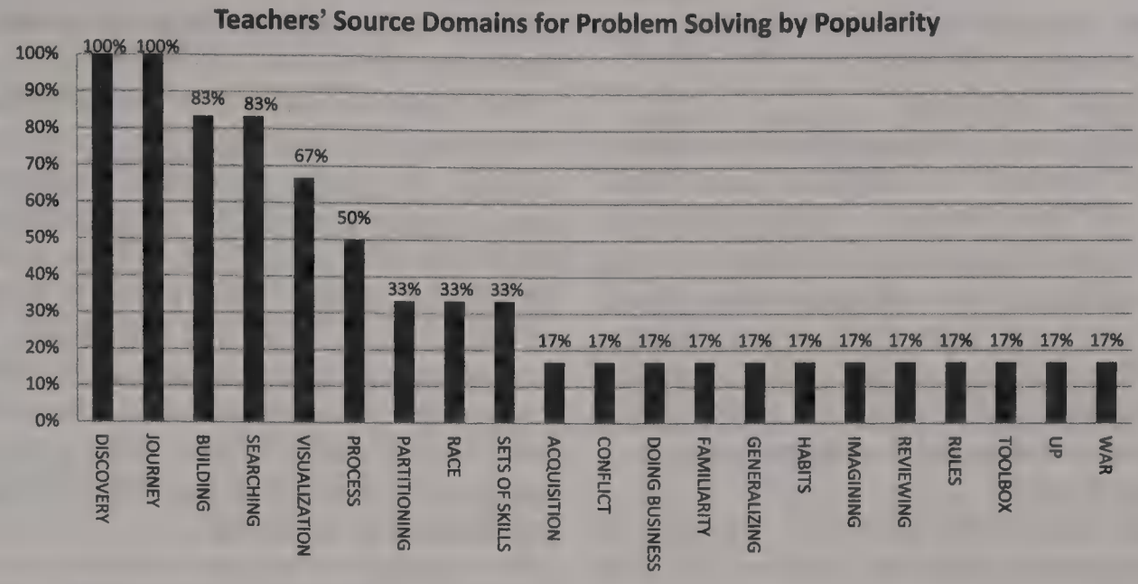


Figure 6. Percentage of teachers (per interview) that used each source domain mapped from the source of mathematical problem solving.

Nonetheless, we see the same top seven source domains were frequented and popular with both students and teachers.

Discussion

This study began by asking what metaphors students and teachers use to describe mathematical problem solving (Q1). This question was answered using a qualitative phenomenological method known as CMT analysis. Using qualitative and quantitative analyses, a coherent subset of conceptual metaphors was identified and quantitatively verified (Q2). Seven source domains dominated the interviews among teachers and students in popularity and frequency: PROBLEM SOLVING IS A JOURNEY, DISCOVERY, SEARCHING, BUILDING, VISUALIZATION, PROCESS, and PARTITIONING.

Other encouraging quantitative results included corroborative evidence that the linguistic hierarchy of structural, ontological, and orientational conceptual metaphors was preserved when discussing mathematical problem solving (Kövecses & Benczes, 2010; Lakoff & Johnson, 1980). Our results supported Danesi's (2007) results that students concretized problem solving more

Table 3
Most Frequented and Popular Teacher and Student Source Domains with Exemplars

Source Domain	Person	Prototypical Literal Metaphors
A JOURNEY	Student	"I don't know, that wouldn't have *gotten me too far*."
	Teacher	"We haven't *gone over* this yet so I don't know the specifics."
DISCOVERY	Student	"When I was using my other method I kind of *realized* that that was completely off because it was over 90 degrees."
	Teacher	"Once they *realize* that that's six sides then they'll see that we're looking for rotational symmetry."
SEARCHING	Student	"Since there was a triangle there I knew that if I *found* it, the full length of it, I could do the Pythagorean Theorem."
	Teacher	"My students would have to go *searching* for them [the solutions]."
BUILDING	Student	"I know that if I *add them together* it would equal the same amount of different figures put together because it's just them separated."
	Teacher	"Dividing into parts that you know putting the *full parts together* to get the total amount"
VISUALIZATION	Student	"I can't *see* all the rules for the one shape *in my head*."
	Teacher	"So I think that they will still try to *visualize* what's actually happening as that hexagon is rotating."
A PROCESS	Student	"It is the way that my brain processes it that it just flips or doesn't make sense."
	Teacher	"I think that they're a little bit more comfortable with the *flow chart process* and they know to get right into the geometry part."
PARTITIONING	Student	"You have to *take them apart*, that's what I did, I *took them apart* in my head."
	Student	"I *solved them individually* it's a lot *easier* than having to solve it *all at once*."

frequently with structural conceptual metaphors than ontological or orientational metaphors.

STEM Extensions of This Study

This study focused on mathematical problem solving. However, there is no reason this study must remain bound to mathematics. A viable expansion would be to apply CMT analysis in other STEM fields. Physics education may find similar or different source domains when physics problems are discussed with teachers and students. Ultimately a large-scale study could look to problem solving across multiple STEM disciplines to find sets of coherent structural metaphors and shared experiences.

Implications for Practice

It is vital that practitioners understand that only the *existence* of conceptual metaphor systems has been identified with this study, *not uniqueness.* In Joseph Schwab's (1970) classic, "The practical: A language for curriculum," Schwab distinguishes between theoretical inquiry and practical inquiry. Theoretical inquiry's purpose is comprehension while practical inquiry's purpose is making a decision in a particular situation. Despite different purposes, the overlap of practice and theory is what Lakoff and Johnson (1980) identified as coherence. Rather than looking for an absolute metaphorical system or excepting that no two systems are identical, coherence desires a system which will be close enough theoretically to be beneficial practically. To this end, this research study should *not* be referenced to demonstrate the uniqueness of a metaphorical system, but rather existence. What this research offers is a starting point, a possible set of shared experiences for teachers to try to use in developing a discursive space within their classroom when discussing mathematical problem solving with their students.

Similar to Cassel and Vincent's (2011) preservice elementary teachers' metaphors for teaching, this study's coherent conceptual metaphors offer teachers experiences to explore with students who are struggling when solving mathematics problems. Table 3 offers teachers a set of experiences that students may likely share in solving problems. For example, a teacher may start with the JOURNEY source domain by saying, "when I read the problem, I was just as lost as you were, but to help me find my way, I slowed down and tried to get my bearings by determining what would solve the problem, where I needed to go." In this manner, the imagery (Reynolds, 1993) and experiences of JOURNEY are shared and offer a language from which the student is familiar. Moreover, this use of JOURNEY can aid teachers because it provides a metaphor that can help students "Make sense of problems and persevere in solving them" (MP1, NGA & CCSSO, 2010) with a focus on the journey and not the destination.

In its most basic pedagogical form, CMT allows teachers to be aware of the metaphors they use while teaching. For example, if a teacher is listening and identifies students' literal metaphors referencing the conceptual metaphor of PROBLEM SOLVING IS A RACE, the teacher can diffuse the situation stating, "I don't want to think of problem solving as a race. While you may have to move fast on tests, speed does not indicate your ability to be thorough or that you understand the material." Thus, CMT can offer practitioners a method to listen more meaningfully and be conscious of the metaphors that influence student learning.

Implications for Research

Historically, mathematics education has struggled to identify an accepted definition of problem solving (Schoenfeld, 1992; Shumway, 1982; Silver, 1985; Stanic & Kilpatrick,1989). This study found seven source domains that give a coherent framework from which to describe problem solving that were meaningful and contextual to students and teachers of this study. While there may not be a specific definition given to problem solving that research communities will agree upon, these seven source domains offer research a concrete set of fundamental experiences associated with problem solving.

CMT analysis provided mathematics education with a model (Lesh & Zawojewski, 2007) to interpret students' perceptions and interpretations of problem solving. This model's purpose offered a flexible methodology under which experiences are shared and summarized using conceptual metaphors. This methodology has expansive possibilities for research, but it should be made clear that CMT analysis needs to be limited to certain topics. Mathematical problem solving was an ideal target domain because of its multitude of definitions, yet grounded experiences and contexts. Marcel Danesi (2007) reminds us:

> The dilemma in education, it would seem, has always lied specifically in the teaching of abstract concepts (not concrete ones). It is precisely in attempting to resolve this dilemma that CMT presents itself as a potentially useful framework because it suggests that abstract concepts can be concretized in exactly the same way as concrete ones such as positive and negative numbers. (p. 228)

This concretization mandates the need for an embodied cognition and thus only useful with topics of less tangible understanding that require shared experiential understanding. Future topics to be studied using CMT analysis could include mathematical generalizations, proof,

and reasoning. Thus this study also offers a novel approach to CMT analysis, to interpret the perceptions of teachers' and students' experiences.

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Investigating Changes in Preservice Teachers' Conceptions of STEM Education Following Video Analysis and Reflection

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Nationally, there is a steadily increasing emphasis on the improvement of STEM education. This includes the integration of STEM subjects that have been traditionally taught separately, making it critical that prospective STEM educators are equipped to teach using integrated STEM approaches. Connected, an important challenge is providing preservice STEM teachers with experiences in which they can develop an understanding of how to optimize learning through integrated STEM instruction. A potentially effective way to foster this conceptualization is through video analysis of integrated STEM practices. To investigate this possibility, here we present a semester-long study focused on engaging preservice STEM teachers with observing, analyzing, and reflecting about instructional STEM practices through a video-based intervention. Findings suggest that viewing and reflecting on integrated STEM practices may enhance preservice STEM teachers' conceptions of integrated STEM approaches, representing a practical method of preservice STEM teacher professional development.

Recently, the President's Council of Advisors on Science and Technology (PCAST) recommended that 100,000 new Science, Technology, Engineering, Mathematics (STEM) teachers be prepared with strong teaching skills and content knowledge by 2020. Moreover, current reports by the National Research Council and National Academies of Engineering have called for shifts in approaches toward integrated STEM instruction (NAE & NRC, 2014; NRC, 2013). Integrated STEM addresses the need for both explicit and intentional integration of STEM subjects, emphasizing cross-cutting concepts, core disciplinary concepts, and viewing science as a set of practices (NGSS Lead States, 2013). It has been shown to enhance students' problem-solving skills and science content knowledge (Wendell & Lee, 2010). Thus, numerous curricula, models of enactment (challenge-; project-; problem-; design-based learning), and professional development models have been developed (Guzey, Tank, Wang, Roehrig, & Moore, 2014; Brophy, Klein, Portsmore, & Rogers, 2008; Cunningham & Hester, 2007; Sun & Strobel, 2013).

However, integrated STEM instruction presents various classroom challenges, leading to a resistance toward implementation (Liu, Carr, & Strobel, 2009). Along with a cited lack of time, resources and support (Lee & Strobel, 2010), and a range of integrated STEM conceptions held by teachers (Radloff & Guzey, 2016), adoption of integrated STEM requires adapting current science instruction toward this more novel, interdisciplinary approach (Cunningham, 2008). This means recognizing and utilizing integrated STEM approaches, requiring teachers possess adequate conceptions of integrated STEM (as pedagogy; a set of disciplines and associated content) supported by effective learning opportunities. Yet, often integrated STEM instruction is not an intentional part of teacher education programs, and most preservice and in-service teachers lack adequate integrated STEM exposure (O'Brien, Karsnitz, Sandt, Bottomley, & Parry, 2014).

As an effective, practical means of STEM exposure and teacher development, we investigated whether simply *viewing*, *analyzing*, and *reflecting on* a set of short video examples of effective integrated STEM teaching would allow preservice teachers to gain a deeper understanding of integrated STEM. While viewing, analyzing, and reflecting on videos of teachers' own and others' teaching has been shown to *generally* enhance conceptions of teaching practices and classroom interactions (Tripp & Rich, 2012), studies focusing on integrated STEM teaching and learning are scarce. However, videos represent a practical pedagogical tool for teacher educators, as well as a much-needed source of potential development for preservice STEM teachers. We focused on the following question: How does repeated observation, guided analysis, and reflection over a series of short integrated STEM videos affect preservice elementary teachers' conceptions of integrated STEM?

Integrated STEM Education

Exemplifying integrated STEM, Moore, Johnson, and Peters-Burton (2015) provide the following definition: "the teaching and learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies"

(p. 24). Herein, the authors discuss six central components of every integrated STEM unit or activity, including: (a) relevant and engaging contexts, (b) engineering design challenges, (c) elements of failure and redesign, (d) standards-based math and/or science aims within real-world problems, (e) student-centered teaching approaches, and (f) an emphasis on teamwork and communication abilities. While we acknowledge no integrated STEM conception is "better" or "best," this definition provided an informed basis for integrated STEM learning. It also suggested tangible, easily visible examples of both integrated STEM content and pedagogy for viewing in videos.

Video-Based Interventions

Previously, video-based interventions have been effective for reflecting on teacher practices and classroom interactions (Abell, Bryan, & Anderson, 1998; Bryan & Recesso, 2006; Copeland & Decker, 1996; Rich & Hannafin, 2009), increasing effective teaching behaviors (Hougham, 1992), gaining new classroom perspectives (Sherin & van Es, 2005), and identifying gaps between teaching beliefs and actual practices (Manzi, Preiss, Flotts, & Sun, 2008). One underlying mechanism has been identified as *teacher noticing*, or what teachers focus on in videos they are shown (van Es & Sherin, 2002). According to van Es & Sherin, *noticing* consists of three facets: (a) recognizing what is important in given teaching scenarios, (b) using contextual knowledge to reason about those scenarios, and (c) connecting specific aspects or events back to teaching and learning principles.

Over time, what teachers notice has been found to move initially from classroom management toward student thinking and interactions (van Es & Sherin, 2008). Results in the integrated STEM classroom suggest enhanced mathematics and science teachers' ability to both *notice* and *interpret* significant classroom events, as well as gain a deeper understanding of science content and learning trajectories (Abell & Cennamo, 2004; Goldman, Pea, Barron, & Derry, 2007; Johnson & Cotterman, 2015). Yet, as Rodgers (2002) discusses, teachers often perceive classroom interactions differently within the milieu of new reform.

Concerning methodological approaches to video analysis research, effective studies have summarily consisted of: (a) viewing a series of their own or other teachers' videos of classroom instruction; (b) selecting events of focus in the video (e.g., student's mathematical thinking); (c) evaluating or interpreting these events (Sherin & Russ, 2014). These correlated with *viewing*, *analyzing*, and *reflecting*, and have been performed through video clubs, discussion groups, or written responses (Bryan & Recesso, 2006; Sherin & Russ, 2014; van Es & Sherin, 2008). Time of video, number of videos, and scaffolding surrounding video analyses (e.g., guided vs. unguided reflections) varied widely (Tripp & Rich, 2012).

Here, we used van Es and Sherin's (2002) aforementioned framework of *teacher noticing* in combination with effective video methodology (observing, analyzing, reflecting—Tripp & Rich, 2012) to guide our study. We aimed to understand the effects of observing, analyzing, and reflecting on only five, short (15-minute) videos (1.25 hours total) depicting effective integrated STEM teaching using guided reflection.

Methods

Descriptive case study methodology was used in guiding this study (Yin, 2013). The participants were two senior, Anglo-female preservice teachers in their final semester in the Elementary Education program at a large, Midwestern research university. They were conveniently located and in their last semester at the university where this study took place. Other potential volunteers cited "lack of time" as an issue. Spanning a semester (16 weeks), participants engaged in: (a) a preinterview to gauge perceptions and understanding of integrated STEM education, (b) viewing, analyzing, and reflecting over five, 15-minute integrated STEM teaching videos, and (c) a postinterview. Videos were given approximately every 2.5 weeks.

The sequence of videos consisted of a "control" video (shown first and last; a premeasure and postmeasure to gauge conceptual changes), and three other video cases. The video clips that were used in this study were 15-minute, edited clips of videos found online at the Teaching Channel public website (https://www.teachingchannel.org/) and at the Engineering is Elementary website (www.EiE.org). They were: a roller coaster design, heat loss unit, bridge building, and hand pollinator design. Camtasia video editing software was used to remove any teacher reflections in the videos beforehand so as not to influence participants' thoughts. All the videos were aligned with the conception of integrated STEM education (Moore et al., 2015), and contained students: actively engaged in standard-based integrated STEM content and practices; working on real-world problems; in small groups; designing, testing, evaluating, redesigning and communicating engineering solutions; using relevant technology.

Preinterviews and Postinterviews

Preinterviews and postinterviews were semistructured, and consisted of 10–11 open-ended items (pre, 10; post, 11) to understand participants' conceptions of integrated STEM before and after the video intervention (see Appendix). The added item in the postinterview was to a

question asking participants to self-report on the effectiveness of the intervention.

Video Analysis and Reflection

Video analysis and reflection were separate tasks. Analysis consisted of participants being prompted to analyze four aspects of an integrated STEM classroom while watching the videos: (a) *Teacher Pedagogy* (what teacher is doing); (b) *Students* (what students are doing); (c) *Assessment*; (d) *Example of STEM Integration* (whether or not the current activity was an example of integrated STEM approaches). If participants saw anything interesting, it was suggested that they pause the video and respond to the following questions: What do you notice? What is your evidence and interpretation of what took place? These prompts scaffolded teachers to learn to *attend to*, *reflect on*, and *reason about* teaching and learning (van Es & Sherin, 2008).

After watching a video, participants were provided with a series of three guided reflection questions. These questions attempted to gain a deeper understanding of participants' changing conceptions in conjunction with the video coding, asking:

1. Did this video provide an example of a lesson/unit utilizing STEM integration? How do you know?
2. What components of an effective integrated STEM lesson were represented in this science classroom? Which were missing?
3. How did this lesson/unit differ from what you would consider an effective science lesson/unit? If you felt like it was effective, explain what the teachers and students did that made you feel like it was effective. If you did not feel it was an effective lesson/unit, please explain what you would do differently.

Secondary Data Sources

Participants created five lesson plans to implement during student teaching as part of normal classroom work (separate from the video intervention). Immediately after postinterviews we asked if they would volunteer any of these plans, and compared them with Moore and colleagues (2015) six main components of an integrated STEM unit.

Data Analysis and Interpretation

Our analysis served two purposes. The first was to explore the effects of video analysis on teachers' understanding of integrated STEM practices by comparing their comments for prevideo and postvideo analysis tasks. The second was to see how video analysis support *changed* participants' understanding of STEM integration. To do so, preinterviews and postinterviews were transcribed, and teachers' comments from the video reflections were extracted. We then read the data set multiple times, and generated assertions individually and collaboratively, repeatedly examining the interview transcripts and reflections for instances that supported our assertions (Erickson, 1986). For example, we systematically looked for confirming as well as disconfirming evidence for the assertion about change in participants' conceptions of integrated STEM. Afterward, we performed both *within* and *cross-case* analyses (Yin, 2013). During our weekly research meetings, we discussed, developed and compared case descriptions for each participant.

Results: Preservice Teacher Case Studies

Case 1: Jill

Background. Jill was a senior in the Elementary Education program at the university where this study took place. She had taught English for roughly three semesters (through the teacher placement program), and ultimately desired to teach at the K–2 level in her home town. Jill was in her early twenties, from a middle-class, Anglo-family. Not previously interested in integrated STEM education, she had not thought about it prior to the first interview 'other than one lesson in her elementary science methods course' in the previous semester. When asked to define integrated STEM, she replied, "I really don't remember what it stands for, haha, maybe the 'S' is science?" Ironically, her own science experiences were her driver for participating in our research. She said, "I mean. . .because I don't have memorable experiences from elementary school in science, I kind of want to change that for my future students—make it more engaging, and learn and incorporate more about STEM."

Initial conception of integrated STEM. Jill did not have a well-defined initial conception of integrated STEM. Furthermore, she suggested that traditional science units and integrated STEM units do not differ. However, she did advocate integrated STEM as a more effective approach because of more subjects being "meaningfully" taught together. "Which one is more effective? Hm. . .probably integrated STEM. . .it expands beyond the science unit. . .within STEM you can teach the science unit with more meaningful purpose" she said.

Jill also thought "informal" (formative) assessments should be utilized in the integrated STEM classroom. She stated, "Informally, I would definitely be going around the room asking them questions. . .perhaps having a discussion with each student to formally assess 'what did you get out of this? Do you see, like, the point we're making here?'" Finally, Jill suggested all STEM disciplines were fully connected, ". . .because now I remember this conversation in class, because science, technology, engineering and math, you can't have one without the other." She started

remembering a class discussion from the previous semester just as the interview ended.

Video analysis and reflections. Through the first two videos, Jill's video reflections focused heavily on what integrated STEM disciplines were being represented in each unit, how often they were represented, and literally stating what activities were taking place. When reflecting over the control video (roller coaster design), Jill reflected under the "Example of STEM Integration" category: "Design the optimal coaster that's the longest that will keep the marble on," and later, "Seeing if their coasters work." She did the same for each category of coding ("Teacher Pedagogy," "Students," "Example of STEM Integration"; see Appendix). She emphasized integrated STEM as the set of disciplines in her reflections, writing:

> This video does utilize STEM integration into its lesson/unit. I could see the students and teachers incorporating all of the aspects of STEM: science, technology, engineering, and math.

When asked to discuss how the unit differs from an effective science unit, she indirectly referred to group work and active learning, and focused on the teacher's guided questioning.

> I felt that the teacher gave the students a lot of opportunities to interact with one another. It wasn't a situation where the teacher lectured the students. . .It was also effective because the teacher probed students for questions and misconception.

Throughout the next three videos, Jill's language in her reflections changed, more closely correlated with using contextual knowledge to reason with presented scenarios; the second facet of teacher noticing (van Es & Sherin, 2002). She started spending more time describing activities and thought processes related to what constituted an integrated STEM unit. For example, after viewing the second video (about heat loss) under the "Student" coding category she coded: "Students are figuring out where they can better construct their model." Under the "Teacher" category she wrote that the "teacher left instructions vague so that students could learn for themselves so that they wouldn't do a good job at construction (at first)." When reflecting, Jill pointed out the teacher functioning as a facilitator, allowing students to fail—one of the main components of an effective integrated STEM unit.

Reflecting on the third video (bridge design), Jill mentioned engineering design. Although mentioned or done in all videos, this was the first time she mentioned it. She wrote under the "Student" coding category that students "Learn about the steps in the engineering design process." Recalling the heat loss unit, she also (surprisingly) reflected that allowing the students to fail could have constituted an improvement to the unit. She wrote:

> It would have been cool for the students to have been able to build a bridge. . .and fail so that they could learn that they need to build a bridge that can support the force that is being put on it.

While watching the fourth video, in which second-grade students designed and tested hand-pollinators, Jill coded under the "Example of STEM Integration" category: "Students work together to identify the engineering steps" and "students find ways to solve orchid's problems." She wrote about the teacher "helping students to identify problems and solutions."

> I noticed that all of the students were engaged in the lesson and had the opportunity to read, design, and build. . .I really liked that it provided students the opportunity to identify ways in which they could improve.

Finally, Jill watched and reflected on the control video again. This time around, examples of coding under the "Example of STEM Integration" included: "Engineering-design with physics of a roller coaster," and "Students discuss kinetic and potential energy with their marbles." In the "Assessment" category she wrote that "(students) write down why it was a failure and one modification they would make to their design." Reflecting, Jill expanded that: "All of the components were present and effective in this STEM lesson in the science classroom. I really liked seeing how they worked together in order to create a lesson that was meaningful to the students and promoted higher-order thinking." However, she still referred here to integrated STEM as a set of disciplines with associated classroom activities.

> Science was used throughout. Technology was used after students created a model of their roller coaster. . .Engineering was big, designing their roller coasters. I really liked that the teacher called her students engineers because I feel that it makes the lesson more realistic for the students. Math was used to create measurements for different pieces of their roller coaster.

Lesson Procedures:

1. The teacher will begin by engaging the students in a conversation about simple machines in order to review what they learned at Imagination Station for their field trip.
2. The teacher will then provide students with the opportunity to create their vehicle.
3. Students will be allowed to explore the given materials and chose what they think will be the best in helping them build their simple machine vehicle.
4. At this time, the teacher will walk around the classroom and provide scaffolding as needed.
5. After this, the teacher will ask the students to place their simple machine in front of a fan to help them observe how a force acting upon their vehicle helps make it go forward.
6. The teacher will then have a discussion with the students about their simple machines.
7. The students will then complete their assessments in two ways:
    a. Through writing in their journal
    b. Completing a provided handout

Figure 1. An excerpt of Jill's simple machine lesson plan.

When reflecting about why the unit was effective, she talked about students being eager to participate and engaged with the engineering design process, writing:

> The students were super eager and willing to participate because they were given particular roles (during designing). I also liked that all of the components were incorporated. I could see myself doing a lesson like this.

Postinterview. To remind the reader, Jill's preconception of integrated STEM was undefined. Now she laughed, saying "alright haha, (integrated STEM is defined as) science, technology, engineering, and math. And incorporating STEM into your classroom in regards to a science classroom is incorporating all those components to make a lesson." While suggesting that all STEM disciplines comprise a more effective integrated STEM unit, she also acknowledged not all need to be present all the time. "Well...after watching the videos and learning more about STEM I found that some teachers incorporate some aspects of STEM and some teachers incorporate all of the aspects," she said. Jill also emphasized the importance of hands-on activities. "I think the more students can actually see things in front of them and manipulate them themselves the more they'll realize it's real life." She then mentions how:

> The cool thing...was that they (the students) weren't really using the textbook... you're using more resources than the textbook. It's like, newer concepts we're trying to introduce, so textbooks aren't going to incorporate all of those aspects.

Most surprisingly, Jill said she had already adopted integrated STEM teaching for herself in her teacher placement classroom. She said, "Having students fail wasn't something that I would have thought to do until I watched that video, and then my mind was blown! I was like 'Wow, we can let the students fail!'" She smiled, letting on that:

> Actually, after that I created a lesson at one of the schools I was at this semester, and we talked about simple machines, and so they got to build their own toilet paper tube simple machine that's a car, for a wheel-and-axle, and so I just gave them the materials and just let them go to create it. But it wasn't until they saw my model that they were able to make improvements from theirs. So that was definitely something I took moving forward.

Lesson plan. Jill eagerly volunteered her lesson plan. While the lesson plan was organized using Bybee's 5E Instructional Model, Jill highlighted all she had learned from watching the videos. While doing so, her idea contained different integrated STEM content than was found in any videos. Figure 1 shows an excerpt of the lesson plan.

Change in conception. As shown through excerpts from the initial interview and throughout the reflections, Jill's conception of integrated STEM changed through the course of the intervention. Comparing the first and last video reflection (of the same control video), her emphasis shifted from more focused merely on the STEM disciplines to emphasizing activities taking place in conjunction with each discipline. Although Jill still seemed to widely consider integrated STEM education centering on each STEM discipline being present in the unit, in the postinterview she differentiated that not all disciplines need to be present in each unit. Throughout the reflections, she also highlighted the facilitative role of the teacher, as well as teamwork, designing, redesigning, and student engagement.

Case 2: Anne

Background. Anne was an Anglo-female senior in the Elementary Education program. During her initial interview, she described growing up in a Midwest, urban setting. She cited having a lot of experience with diversity, and wanted to teach in urban settings. She also talked about having positive science experiences and influential teachers, but how math was always her favorite because of the way her teachers "contextualized the problems within science or other disciplines." She talked about teaching math and observing science taught in her teacher placement classroom, and had previously heard of STEM integration.

Initial conception of STEM. Anne had a unique initial conception of integrated STEM. While she knew that it stood for Science, Technology, Engineering, and Math, emphasis was placed on integrating STEM with other non-STEM disciplines. She said in her initial interview:

> STEM integration would be utilizing those [STEM] fields to teach other [disciplines], or vice versa, so like, using Language to teach Science, Technology, Engineering, Math. Um, I don't really know I see it much different than any other type of integration. . .

She was also very skeptical of using integrated STEM, because as she described it: "I think that if you use one [discipline] to teach the other, you set yourself up to get to the risk of not actually teaching one, because that focus has to be on something, ya know?"

She thought integrated STEM should be assessed formatively through attempting to investigate the "driving creativity of it," and suggested a facilitative role for the teacher." All classes should be characterized by discovery learning," she said, or "mostly student-driven."

Video analysis and reflections. Anne's video reflections progressed from more of an emphasis on broad integration and literal descriptions of activities, to more specifically STEM integration and why activities were taking place. For the first two videos, Anne focused mainly on activities emphasizing integration. Under the "Example of STEM Integration" coding category, Anne explicitly included the word "integration" into the majority of her coding. She wrote: "measuring lengths and recording in table is integrating math," and "using Newton's Laws of Motion to support design and materials used is integrating science." By the second video, she started labeling the integration. She coded "using thermometers and iPads = technology," and "math integration with working with measurements." Like Jill's reflections, rationale for activities was absent and activities were literally described.

She defined integrated STEM during her reflections mainly as the set of disciplines, as well as broad integration (STEM vs. Non-STEM). Reflecting on the control video she wrote:

> This video is an example of a lesson/unit utilizing STEM integration. Each of the content areas that make up STEM was involved in the lesson. The students were participating in self-discovery learning and integration with language arts.

She offered that the second video case (heat loss) differed from a science unit through its real-world context—a central component of effective integrated STEM units (Moore et al., 2015), saying:

> This lesson was different than effective science lessons I have seen because. . .students are working in a realistic context–one that is familiar to everyone (the idea of a building losing heat). They were able to see how this lesson related to their everyday lives, whereas other science lessons fail to make that connection/with students.

Reflecting on the third video (which was about bridge-building), Anne started labeling activities with multiple disciplines. For example, under the "Examples of STEM Integration" category she coded: "Math integration by counting, engineering with structure application, science with force concept." In the "Student" category she now focused on designing and materials. She wrote: "Design a bridge idea and explain how each piece will be used," "offer input as to what different materials could be used," and "design bridge and draw design." In the "Assessment" category she explained "explaining their designs to check for reasoning as to why it was strong."

When answering the reflection questions that followed her coding, Anne pointed out the purposeful integration present in the unit. "I think this is good evidence of proper integration as it was seamless. The components of STEM each served a meaningful and intentional purpose in the lesson. For example, the math integration was not simply added to meet the math requirement–it had a purpose in helping the students learn," she wrote.

For the fourth video (designing hand-pollinators), Anne interestingly suggested that it was a more interdisciplinary unit. Within the first minute of the video under the "Example of STEM Integration" category she coded "The story talked about engineering and science; this was more interdisciplinary than STEM." In the "Assessment"

category, Anne again emphasized why students did certain activities, writing: "Talking with small groups to get an idea of their thoughts about a design," In her reflection questions she describes in more detail why she did not consider it an integrated STEM unit:

> This lesson missed some fundamental components. I felt that this teacher played too much of the role of the "answer-giver" rather than facilitator. Math was absent from the lesson and you cannot have an effective lesson that utilizes STEM integration by leaving out one of the key components of STEM.

Instead, Anne labels it as "an effective science unit" as students are still able to see the "bigger picture" and connect what they learned to the real world.

Finally, Anne reflected again on the control video. Her coding was very similar to the fourth video. Again, in the "Example of STEM Integration" category she started by coding "The story talked about engineering and science; this was more interdisciplinary than integrated STEM." However, she was able to code for all integrated STEM disciplines this time, and thus later considered it an integrated STEM unit. Under the "Assessment" category she wrote about group discussion, formative assessments, students reasoning with materials, and seeing if students can answer the "why" questions that are asked by the teacher following the design task. "If they [the students] can (answer), they really understand the concepts and if not then they may only have a contextualized understanding of the key ideas" she wrote. Reflecting, Anne demonstrated a complete understanding of STEM integration, writing:

> Each of the content areas that make up integrated STEM were obvious and purposefully utilized in the lesson—seamless integration. The students were curious, asking questions and seeking understanding and answers using math, scientific concepts, models, etc. The design process focused on engineering and required the use of technology to aid in this process.

Here she demonstrated an understanding that encompassed both concepts and activities. When asked how the unit differed from an effective science unit, Anne responded that:

> This lesson was effective because it was student-centered. The students were working as a group and they were communicating their ideas using appropriate vocabulary/terminology. The teacher was the facilitator as seen by her prompting and questioning. The students were able to share their thinking and reasoning with her.

Postinterview. To remind the reader, Anne's initial conception of integrated STEM could be characterized as the STEM disciplines, plus broad integration. In the postinterview, Anne's integrated STEM definition changed slightly, aligned with her video reflections. She stated, "STEM is Science, Technology, Engineering, and Math, to do it in that order, haha. So, um, I think the integration of it is like, seamlessly having all those pieces together and having it make sense in the lesson." Defining "seamlessly," she said that someone coming into the classroom "should not be able to tell really" what disciplines are being taught, but that they are "cohesive and together."

Anne also cited more fully understanding the value of performing hands-on activities compared with rote learning activities. She said hands-on activities really help students to transfer material they've learned, and reflected on her own K–12 science experience:

> I always thought that like the science units I loved the most, they really were integrated STEM lessons. Ya know, I think that they were the most misclassified as science units, because they did integrate math, and they did integrate things like the engineering piece. Like, we got to build things and test them. And we used resources and materials that could be the technology piece. So I think that the science ones that I guess weren't as. . .fun, haha. . .they tended towards more of drill and practice (rote learning).

When asked about the effectiveness of integrated STEM, she replied that units are much more effective than traditional science units because of the real-world context, which "could really help kids want to learn it more, and that it does really matter." As far as assessment, she now suggested that through design tasks that rubrics should be used to assess students.

Overall, Anne said that the intervention itself was helpful to her in understanding integrated STEM. Skeptical of teaching using integrated STEM approaches to begin with, however, Anne now talked about *newly found* barriers. Due to her familiarity with urban school settings, Anne discussed limited resources or funds for teachers as definite barriers to teaching using integrated STEM approaches. She also talked about the crippling feeling of having so many standards to follow. She says sadly that "I guess if I saw. . .release on like, the leash on teachers, ya know? It's like, there's so many strict, like, 'teach this today, do this

today,' and there's not really any room for creativity, or. . .we're experts in our field! I know this is an effective teaching method."

Lesson plans. Anne provided us with numerous lesson plans, but none were integrated STEM units because the school she was currently teaching at did not have adequate resources, and furthermore had strict expectations of teachers to "meet standards." Of the five disclosed lessons, three of them were math-centered (adding/subtracting/taking measurements using tools) and two covered topics in biology (animal relationships/life cycle of a frog). In her lessons, Anne clearly emphasized science skills such as interpreting data and using evidence to support claims.

Change in conception. Anne's conception of integrated STEM changed through the course of the intervention. Because she had a more-defined initial conception, as well as more teaching experiences, changes were better reflected in the way that she viewed and discussed integrated STEM. Her initial conception highlighted integration—between STEM and Non-STEM disciplines. She also was unsure of how integrated STEM would be assessed. Following the intervention, Anne's conception became more focused. She talked about "seamless" integration and STEM-specific activities such as designing within a real-world context in which "students' curiosity and engagement would drive the unit." Her attitude also changed. Whereas she initially showed little interest in teaching using STEM approaches, following the intervention she had not only expressed interest in using integrated STEM teaching, but had clearly identified what barriers are currently holding her (and other teachers) back from currently doing so.

Discussion

Using van Es and Sherin's (2002) teacher noticing framework in conjunction with current video-based intervention best practices (*observing*, *analyzing*, *reflecting*—Tripp & Rich, 2012) and videos of integrated STEM teaching, results presented here suggest that participants began to conceptualize integrated STEM differently than before the intervention. Findings also echo literature suggesting video-based reflection may support teachers to consider and evaluate their views of teaching and learning (Abell et al., 1998; Seidel, Stürmer, Blomberg, Kobarg, & Schwindt, 2011; Sherin, 2007; Sherin & Russ, 2014). Participant conceptions became more aligned with what Moore et al. (2015) consider to be the six central components of every integrated STEM unit, after immersed in only 1.25 hours of video. Interestingly, this understanding was most expressed through preinterviews and postinterviews, while both participants maintained a focus on integrated STEM as a set of disciplines throughout their analyses and reflections. One reason we hypothesize for this difference is that specific integrated STEM activities were not explicitly named or discussed in the videos, yet were evident for the preservice teachers to notice. Therefore, we suggest most instances of preservice teachers' using specific integrated STEM-related terms were either: (a) previously held pedagogical terminology being recognized in the videos and transferred to, or recalled during their reflections, or (b) understanding gained through watching the videos. Likewise, teachers could have also had difficulties with analyzing and reflecting versus discussing what they noticed verbally with the researchers (van Es & Sherin, 2008). Concurrent teacher placement experiences (e.g., implementing integrated STEM) may have influenced results as well.

Similarities in Conceptual Change Surrounding STEM Education

As mentioned above, both participants seemed to begin to recognize integrated STEM through video analysis. This included not only integrated STEM content and pedagogy, but contextualization and assessment as well.

Integrated STEM content (as well as discipline) was largely the anchor by which participants organized their coding. This suggested high importance placed on content even before the intervention, or perhaps a familiar entry point from which to build their conceptions. Pedagogically, integrated STEM was denoted as a student-centered approach in which the teacher serves as a facilitator, highlighted by groupwork and the usage of the engineering design process. Design terms such as "failing," "redesign," and "engineering design process" began to appear in participants' coding as each video was viewed and reflected upon.

Contextualization became recognized as setting integrated STEM lessons within "real-world scenarios" in which students can "apply their knowledge" through hands-on activities. Contrasting some initial participant skepticism, integrated STEM became an authentic and relevant approach. Surrounding assessment, participants recognized formative evaluation and the use of rubrics. Participants especially pointed out aspects of design planning in which students must test and evaluate materials toward building their designs.

Aside from a recognition of specific integrated STEM-related activities, both preservice teachers also seemed to gain an awareness and appreciation for purposeful integration of STEM disciplines. In the preinterview, one of the two participants neither mentioned integration nor spoke about how STEM disciplines were connected. Yet, in

the postinterviews, both participants discussed "seamless integration," in which an observer of an integrated STEM lesson cannot tell what discipline is being taught. This was an especially encouraging finding based on previous work showing a wide range of conceptions surrounding integration of STEM disciplines (Radloff & Guzey, 2016).

Differences in Conceptual Change Surrounding STEM Education

Yet, some aspects of conceptual change also differed. For one, Anne's postintervention conception was more focused on fine details of integrated STEM than Jill's. We suggest this was due in part to Anne having more experience with teaching and observing STEM disciplines, or in other words, being able to better recognize important aspects of teaching scenarios (van Es & Sherin, 2002). She also had a fairly defined initial conception. While Jill worked on creating a conception of integrated STEM, Anne (already possessing a conception) was able to flesh out what made integrated STEM approaches feasible to utilize in her classroom, as well as what barriers existed. Anne also focused more on how it was being assessed, and suggested one reason she liked the videos so much was that they provided her with resources. This suggests that she had formed a strong conception and was grateful to collect more examples of integrated STEM, although she was not able to use them presently. While nonetheless remarkable, Jill's conception seemed broader and less detailed than Anne's. However, following watching and reflecting over the videos, Jill felt comfortable enough creating and implementing an integrated STEM lesson. We suggest perhaps her shallow initial conception and lack of perceived barriers had led to her taken actions. An absence of initial feelings toward STEM could make one either more or less critical of implementing it themselves. Yet, both participants mentioned the videos helping positively change their conceptions of integrated STEM.

Conclusions

Following video observation, analysis, and reflection, Anne and Jill appeared to gain both more informed, focused conceptions of integrated STEM education, not evident during preinterviews. They noticed aspects of integrated STEM teaching ranging from pedagogy to student interactions, as well as components of effective STEM units (Moore et al., 2015). Although reflecting seemed difficult, they were both able to internalize and reflect on how they could use integrated STEM in their own classrooms. This resonated with findings from previous video-based intervention literature (Abell et al., 1998; Sherin, 2007).

As integrated STEM approaches become utilized in more classrooms, preservice teacher programs need to be modified to offer relevant, reform-based teacher instruction and professional development (NAE & NRC, 2014; NGSS Lead States, 2013). While not generalizable, our findings suggest what observing, analyzing, and reflecting on integrated STEM teaching approaches could achieve conceptually toward that goal. Although more research is needed, so are short and effective interventions that offer simple, low-cost steps in helping with effective teacher development.

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Appendix

Presurvey

The presurvey consisted of ten open-ended questions to get a baseline conception of STEM education. The postsurvey was the same as the presurvey, with the exception of one added question (did you overall find viewing and reflecting on the videos helpful with your own teaching and lesson plan creation?). We have included the presurvey below.

Name _____

Educational Background: _____

Teaching Experience (/grade level taught/discipline): _____

Questions:

1. Do you have STEM teaching experience? If so, how long/what type of experience?
2. How would you define STEM Integration, starting with what the S,T,E, and M, stand for?
3. Why do you define STEM in this way? How did you come to this belief?
4. What do you think are the main components of a STEM unit?
5. Now think of an effective science unit. What do you think are the main components of an effective science unit?
6. How do you think those components of a STEM unit differ from those of an effective science unit?
7. What teaching style have you or would you use to teach a STEM unit?
8. Does this differ from how an effective science unit is taught? If so, how?
9. Which do you think is more effective in respect to student learning (or do you think they are equally effective)? Why?
10. How do you [redacted] STEM student work?

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://www.ssma.org/publications.

Solutions to the problems stated in this issue should be posted before June 15, 2017

▪ **5439**: *Proposed by Kenneth Korbin, New York, NY*

Express the roots of the equation $\frac{(x+1)^4}{(x-1)^2}=20x$ in closed form.

"Closed form" means that the roots cannot be expressed in their decimal equivalents.

▪ **5440**: *Proposed by Roger Izard, Dallas, TX*

The vertices of rectangle ABCD are labeled in clockwise order, and point F lines on line segment AB. Prove that $AD+AC > DF+FC$.

▪ **5441**: *Proposed by Larry G. Meyer, Fremont, OH*

In triangle ABC draw a line through the ex-center corresponding to side c so that it is parallel to side c. Extend the angle bisectors of A and B to meet the constructed lines at points A' and B', respectively. Find the length of $\overline{A'B'}$ if given either

1. Angles A, B, C and the circumradius R
2. Sides a, b, c
3. The semiperimeter s, the inradius r, and the exradius r_c
4. Semiperimeter s and side c.ôôôô

▪ **5442**: *Proposed by José Luis Díaz-Barrero, BarcelonaTech, Barcelona, Spain.*

Let L_n be the n^{th} Lucas number defined by $L_0=2, L_1=1$ and for $n \geq 2, L_n=L_{n-1}+L_{n-2}$. Prove that for all $n \geq 0$,

$$\frac{1}{2}\begin{vmatrix} (L_n+2L_{n+1})^2 & L_{n+2}^2 & L_{n+1}^2 \\ L_{n+2}^2 & (2L_n+L_{n+1})^2 & L_n^2 \\ L_{n+1}^2 & L_n^2 & L_{n+2}^2 \end{vmatrix}$$

is the cube of a positive integer and determine its value.

▪ **5443**: *Proposed by D. M. Bătinetu–Giurgiu, "Matei Basarab" National College, Bucharest, Romania and Neculai Stanciu "George Emil Palade" General School, Buzău, Romania*

$$\text{Compute } \int_{\frac{\pi}{6}}^{\frac{\pi}{3}} \frac{x}{\sin 2x}dx.$$

▪ **5444**: *Proposed by Ovidiu Furdui and Alina Sîntămărian, Technical University of Cluj-Napoca, Cluj-Napoca, Romania*

Solve in $\Re$ the equation $\{(x+1)^2\}=2x^2$, where $\{a\}$ denotes the fractional part of a.

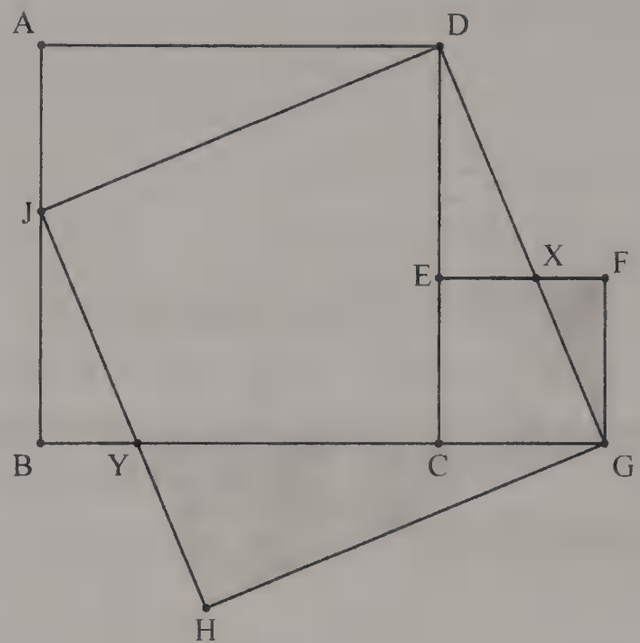
PROBLEMS

section

Ted Eisenberg, *Section Editor*

▪ **5445**: *Proposed by Kenneth Korbin, New York, NY*
Find the sides of a triangle with exradii (3, 4, 5).

▪ **5446**: *Proposed by Arsalan Wares, Valdosta State University, Valdosta, GA*
Polygons *ABCD*, *CEFG*, and *DGHJ* are squares. Moreover, point *E* is on side DC, $X=DG\cap EF$, and $Y=BC\cap JH$. If *GX* splits square *CEFG* in regions whose areas are in the ratio 5:19, what part of square *DGHJ* is shaded? (Shaded region in *DGHJ* is composed of the areas of triangle *YHG* and trapezoid *EXGC*.)



▪ **5447**: *Proposed by Iuliana Trască , Scornicesti, Romanai*
Show that if x, y, and z is each a positive real number, then

$$\frac{x^6\cdot z^3+y^6\cdot x^3+z^6\cdot y^3}{x^2\cdot y^2\cdot z^2}\geq\frac{x^3+y^3+z^3+3x\cdot y\cdot z}{2}.$$

▪ **5448**: *Proposed by Yubal Barrios and Ángel Plaza, University of Las Palmas de Gran Canaria, Spain*

$$\text{Evaluate}: \lim_{n\to\infty}\sqrt[n]{\sum_{\substack{0\le i,j\le n\\ i+j=n}}\binom{2i}{i}\binom{2j}{j}}$$

▪ **5449**: *Proposed by José Luis Díaz-Barrero, Barcelona Tech, Barcelona, Spain*
Without the use of a computer, find the real roots of the equation

$$x^6-26x^3+55x^2-39x+10=(3x-2)\sqrt{3x-2}.$$

▪ **5450**: *Proposed by Ovidiu Furdui, Technical University of Cluj-Napoca, Cluj-Napoca, Romania*
Let k be a positive integer. Calculate

$$\int_0^1\int_0^1\left\lfloor\frac{x}{y}\right\rfloor^k\frac{y^k}{x^k}\,dxdy,$$

where $\lfloor a\rfloor$ denotes the floor (the integer part) of a.

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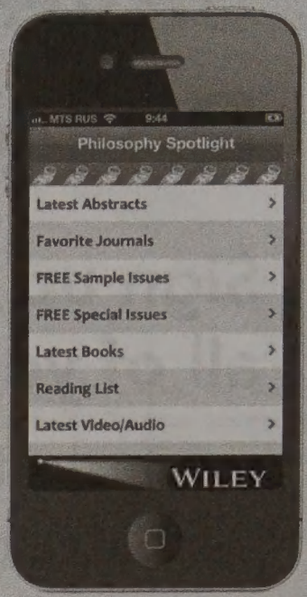

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